Control ENGINEERING

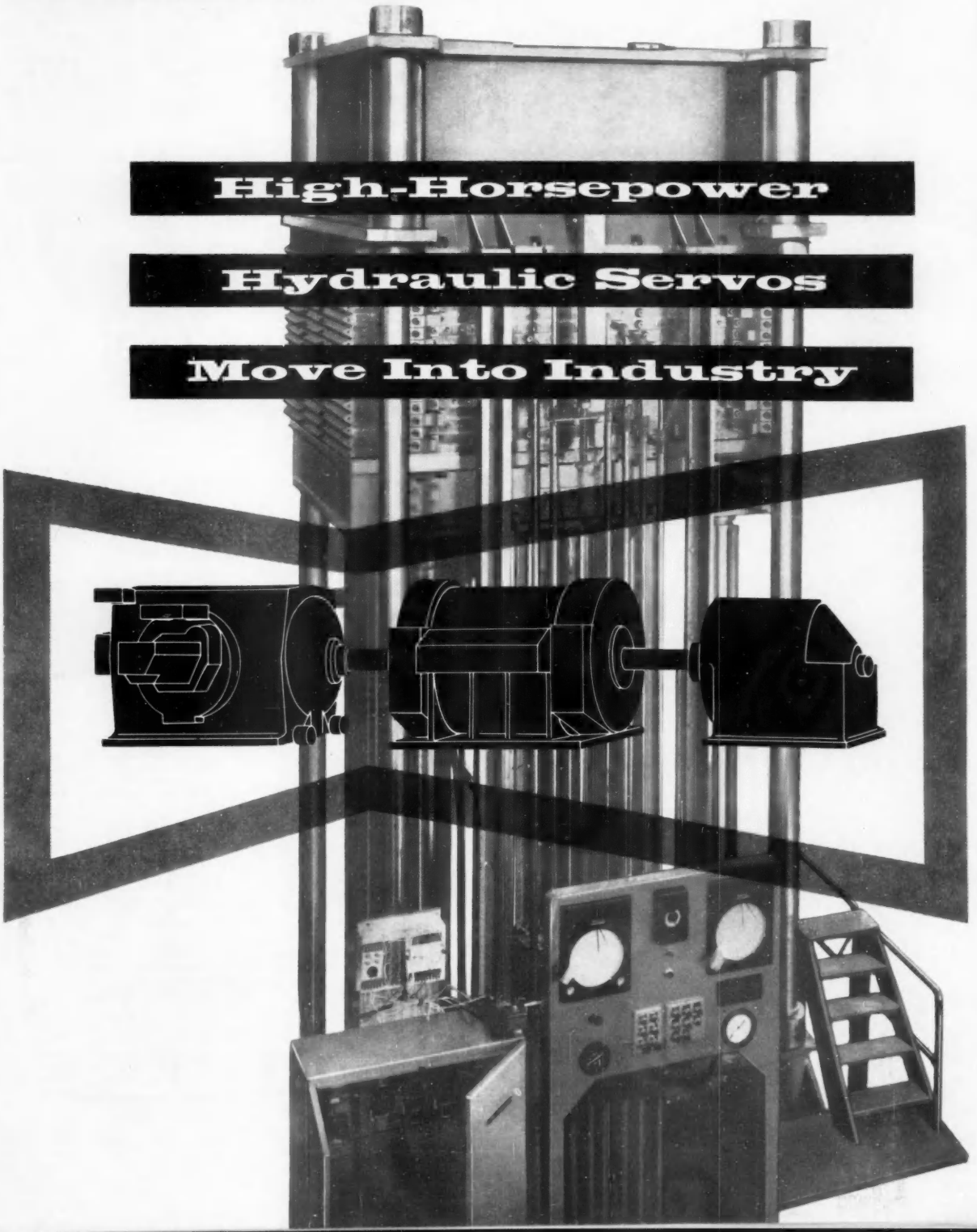
INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

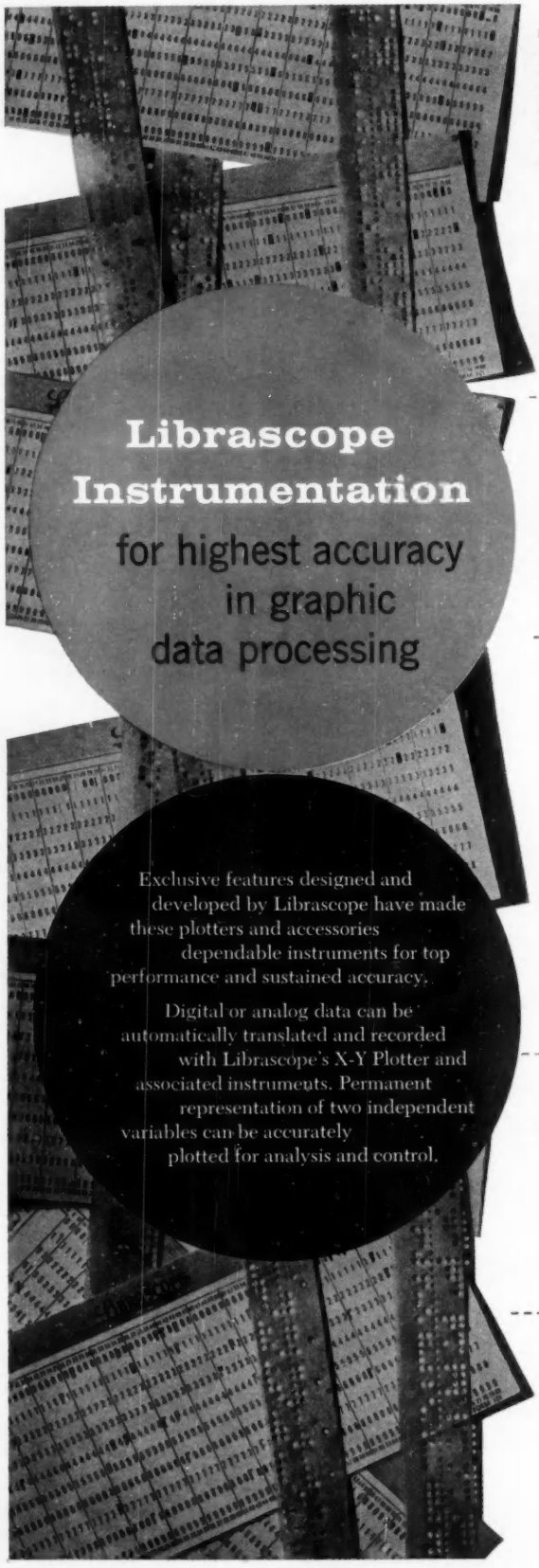
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APRIL 1957

High-Horsepower Hydraulic Servos Move Into Industry





Librascope Instrumentation

for highest accuracy in graphic data processing

Exclusive features designed and developed by Librascope have made these plotters and accessories dependable instruments for top performance and sustained accuracy.

Digital or analog data can be automatically translated and recorded with Librascope's X-Y Plotter and associated instruments. Permanent representation of two independent variables can be accurately plotted for analysis and control.

MODEL 200-B X-Y PLOTTER, used for DC signal input, has full-scale sensitivities of five millivolts, and an input impedance of 1,000 megohms. Utilizing standard reference cells, this model provides drift-free operation. Available external reference voltages may be substituted. Quick interchangeability of input sections is provided. Continuous or point plotting... Rack or case mounted.





MODEL 200-A uses an input of 10,000 ohm resistance potentiometers as an input translator providing 10 to 1 scale expansion and origin positioning. Available standard digital input accessories are essentially inputs of this type. Any resistance potentiometer will provide an analog input for this configuration. Continuous or point plotting... Rack or case mounted.

LIBRASCOPE XY DECIMAL KEYBOARD —This keyboard consists of a three-decimal bank for each axis with associated plus-minus keys. Depressing of the plotting bar initiates plot and clears keyboard automatically. Manual "clear" button is also provided. This unit features Librascope-developed positive-action non-sticking, self-wiping contacts.



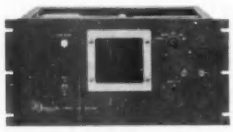


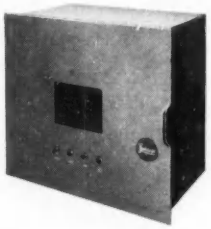
LIBRASCOPE BINARY CONVERTER, MODEL 252 consists of two banks of relays and precision resistors simulating a precision potentiometer. The resistors weight the relays in straight binary so that each bank serves as an input to one axis of the XY plotter. Total resistance is 10,000 ohms per bank. Relays within the converter control the plot cycle.

Mounting: Standard RCA, RMA rack mounts.

LIBRASCOPE PUNCHED CARD CONVERTER —This relay-operated converter accepts three-decimal digit and sign, two channel, IBM punched card information and converts it to analog form for input to XY plotters. Cards can be manually fed through the IBM reading brushes one at a time or automatically read at rates to 50 cards per minute with an accuracy of 0.1%.

Mounting: Standard RCA or RMA rack mounts or in case.





LIBRASCOPE PUNCHED TAPE CONVERTER operates from punched tape reader. Can be modified to operate with any digital computers furnishing a punched tape output. If printed listing desired, unit may be operated from tape-actuated typewriter, such as the Flexowriter. Programming need not be specified on tape. Sequence operation. A particular tape may be programmed to accommodate various tape formats.

Accuracy, ±0.1%.

Career opportunities exist at Librascope for qualified engineers, physicists and mathematicians. Learn about Librascope's new "Creative Project Development Teams." Contact Glenn Seltzer, Employment Manager.

A SUBSIDIARY OF GPE

LIBRASCOPE

Librascope, Inc., 808 Western Ave., Glendale, Calif.

3 *more reasons why only* GEDA *gives you a* custom computer

Chances are the day-to-day solution of *your* design and process control problems has given you a pretty exact idea of what *you* require in analog computing equipment. Chances are, too, that you've been unable to find production computers which just fill the bill. Well, here's the answer to your problem. It's the spectacular GEDA A-14 Series Goodyear Electronic Differential Analyzer.

In the GEDA A-14 Series you'll find more than just 10 years of computer engineering and development experience. You'll find refinements and options that can come only from years of day-to-day operating experience — experience, like yours, in solving the most varied and complex computing problems.

Take, for example, these 3 exclusive servo units:

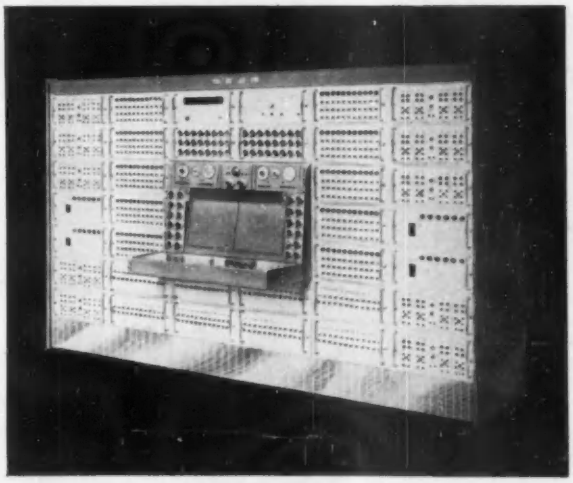
1. High Speed Servo Multipliers on the A-14 eliminate the noise, expense and trouble of a 400 cycle AC power supply, for the A-14 servo motors are DC. Requiring no input choppers or output transformers, the A-14 servos increase reliability and decrease maintenance costs. The high current-low voltage characteristics of DC motors allow the use of transistors, eliminating many troublesome vacuum tube power output stage problems.

2. Servo Function Generators on the A-14 have two linear and four tapped potentiometers. Four plug-in loading cards adjust to set each function and may be stored for future use. The A-14 Servo Function Generators not only produce the function, but also the product of the function and a variable.

3. Servo Resolvers on the A-14 may be used for both inverse and direct resolution and include AGC for high performance operation in inverse resolution application. Another available unit permits electronic integration while generating sine X and co-sine X from dx/dt thus providing continuous resolution.

These and many other advanced design units combine with the exclusive GEDA A-14 console features to give you unmatched precision, capacity and flexibility — truly a custom computer at production economy.

We would welcome the opportunity to discuss the details of a GEDA A-14 installation—large or small—custom-designed to your precise needs. Write: Goodyear Aircraft Corporation, Dept. 931GD, Akron 15, Ohio



GEDA
ANALOG COMPUTERS

The Way To Give Your Hunch a Chance

GOODYEAR AIRCRAFT

GEDA—T. M. Goodyear Aircraft Corporation, Akron 15, Ohio

There's a standard PERKIN model for your every need!

In addition to the 28 volt models featured at the right, the following models are also available:

OTHER 28 VOLT MODELS

Model	Volts	Amps	Reg.	AC Input (60 cps)	Ripple rms
	0-32 V	15		105-125 V 1 phase	2%
	24-32 V	30	±1%	105-125 V 1 phase	1%
	0-32 V	15		115 V 1 phase	2%
	24-32 V	30	±1%	230 V 1 phase	1%
	24-32 V	100	±1%	230 V 3 phase	1%
	24-32 V	100	±1%	230 V 3 phase	1%
	24-32 V	100	±1%	230 V 3 phase	1%

±2%. Also available for 400 V ±10%, 60 cps input. Will be supplied with 230 V input unless otherwise specified.

6-12, 115 VOLT (NOMINAL) MODELS

Model	Volts	Amps	Reg.	AC Input (60 cps)	Ripple rms
	6 ±10%	15	±1%	95-130 V 1 phase	1%
	6 ±10%	15	±1%	95-130 V 1 phase	1%
	6 ±10%	30	±1%	95-130 V 1 phase	1%
	12 ±10%	15	±1%	95-130 V 1 phase	1%
	12 ±10%	15	±1%	95-130 V 1 phase	1%
	12-25	15	±1%	95-130 V 1 phase	1%
	115-125	15	1% rms	230/460 V 3 phase	2%

Immediate Delivery
on standard models available from factory

NEW YORK AREA:
Sales and Warehousing: 1060 Broad St., Newark 2, N.J., MArket 3-1454

CHICAGO AREA:
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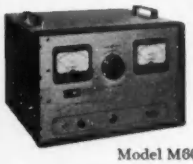
PERKIN...THE LEADER
in tubeless magnetic amplifier regulated
DC POWER SUPPLIES
No Moving Parts • No Vibrating Contacts


Model MR532-15A

2-36 VOLTS @ 15 AMPS SPECIFICATIONS

Regulation:	5-32 Volt Range: ±½% 2-5 Volt and 32-36 Volt Range: ±2%
AC Input:	105-125 Volts, (for 2-32 V.DC), 110-125 V. (for 32-36 V.DC), 1 phase, 60 cps (8 amps)
Ripple:	1% rms max. (@ 36 volts and full load. Increases to 2% @ 2 volts and full load).

Remote Sensing • Vernier Control


Model M60V

0-32 VOLTS @ 25 AMPS SPECIFICATIONS

Regulation:	±1% @ 28 Volts (Regulation increases to 2% over range of 24-32 volts; does not exceed 2 volts over 4-24 volt range. Not stabilized for AC line changes.)
AC Input:	115 Volts, 1 phase, 60 cps (12 amps).
Ripple:	1% rms (@ 32 volts and full load—2% rms max. @ any voltage above 4 volts).


Model MR1040-30A

5-40 VOLTS @ 30 AMPS SPECIFICATIONS

Regulation:	±1% (over entire 5-40 volt range)
AC Input:	100-130 Volts, 1 phase, 60 cps
Ripple:	1% rms


Model 28-30 WXM

24-32 VOLTS @ 30 AMPS SPECIFICATIONS

Regulation:	±½%
AC Input:	100-125 Volts, 1 phase, 60 cps (20 amps). (Unit rated for DC output of 28 volts ±10% for 95-130 volt input.)
Ripple:	1% rms


Model MR2432-100XA

24-32 VOLTS @ 100 AMPS SPECIFICATIONS

Regulation:	±½%
AC Input:	208, 230 or 460 Volts, ±10%, 3 phase, 60 cps (14, 12 and 6 amps respectively). 230 volt input will be supplied unless otherwise specified.
Ripple:	1% rms

Wire factory collect for prices ... Write for catalog.

PERKIN PERKIN
LEADER IN TUBELESS MAGNETIC AMPLIFIER REGULATION

PERKIN ENGINEERING CORPORATION

Control ENGINEERING

APRIL 1957 VOL. 4 NO. 4

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS
Published for engineers and technical management men who are responsible for the design and application of instrumentation and automatic control systems.

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His varied experience began mounting up behind author-of-the-month Hal Levenstein when he received a BEE from The Cooper Union in 1943. Since then Hal has designed radar test equipment, fire-control systems, VHF test equipment, missile-guidance systems, pneumatic servos, and telemetering equipment, and in addition has found time to obtain an MEE from Brooklyn Poly Tech. He joined W. L. Maxson seven years ago and at present is Research Assistant to the Vice President – in other words, the "technical conscience" of the company. During a recent one-year leave of absence he worked on inertial guidance systems in the Instrumentation Lab at MIT, where he developed the response-conversion technique outlined on page 90.

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BONNEVILLE POWER ADMINISTRATION SOLVES SWING EQUATIONS WITH

EASE*

How does an EASE* computer compare with the conventional network analyzer as an aid to electric power transmission engineering?

The answer from Bonneville Power Administration engineers at Portland, Oregon, is indeed favorable. Their Model 1032 EASE* has proved infinitely faster in the solution of swing equations and in studies of transient and steady-state problems of the vast Northwest power network.

EASE computer consisting of Model 1032 receptacle-control, 6 function generators and 20 amplifiers, installed at Bonneville Power Administration engineering offices, Portland, Oregon. Chief engineer is E. C. Starr; computer and systems engineer is Carl Gustafson.*

Interconnecting four of the world's largest hydroelectric projects and hundreds of fast-growing communities, this high-voltage (230 KV and up) network presents complex problems in stability. Speedy problem solution on the EASE* has already enabled BPA engineers to improve system stability, eliminating many outage problems, and to plan a variety of alternate switching paths to minimize circuit downtime.

Indications are that this EASE* installation has already paid for itself, with rosy prospects for a profitable future. Among coming studies BPA engineers plan for the versatile EASE* are:

1. Effect of machine excitation on system performance
2. Hydraulic governor speed control
3. Design problems in mechanical, civil and electrical engineering related to system improvement and future expansion

Good field service is a vital factor in satisfactory computer performance. It is supplied with EASE* by a nation-wide network of factory-trained Berkeley representatives; in this instance, Hawthorne Electronics of Portland and Seattle.

EASE* computation and simulation equipment ranges from the basic Model 1032 illustrated here to the advanced-design Model 1132 with DO/IT (Digital Output-Input Translator system). Two fully-equipped EASE* computation centers (Los Angeles and here at Richmond) are also available on a "for hire" basis. Full information on EASE* equipment and facility services is yours for the asking; please address Dept. L4.

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Beckman®

Berkeley *Division*

Richmond 3, California

a division of Beckman Instruments, Inc.

Design engineers indicate widespread use for

Sylvania Power Transistor Type 2N242

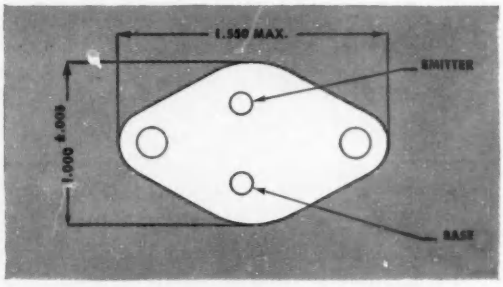
While the type 2N242 is well known for its original use in the output stage of hybrid auto radio, it is rapidly becoming the standard for general purpose use in a wide range of power applications.

There are good reasons for its growing popularity—10 watts collector dissipation, for instance—welded hermetic seal—and a storage temperature of 85° C to eliminate heat problems under idle conditions.

If you have plans for general purpose transistors you'll be glad to know Sylvania's semiconductor plant in Hillsboro, New Hampshire is just about completely devoted to the production of the Type 2N242. That means Sylvania can meet your volume requirements. And, Sylvania's leadership in the manufacture of semiconductors means you're assured of high product uniformity and dependable performance.

GENERAL FEATURES OF THE 2N242 PNP POWER TRANSISTOR—

- 10 watts max. collector dissipation
- 2 amps max. collector current
- 45 volts max. collector voltage
- New welded hermetic seal
- 30 db minimum power gain (typically 35 db)
- 85° C storage temperature
- 100° C junction temperature
- Thermal drop—3° C per watt (typically 2° per watt)



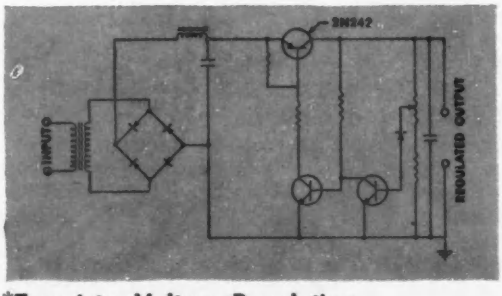
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Here are just some of the applications in which designers are effectively using or planning to use the 2N242



***Transistor Voltage Regulation**

Transistorization of voltage regulator circuits is one of the most popular general purpose applications indicated for the 2N242. Here is a typical regulator circuit incorporating the Type 2N24[illegible]. DC to AC converter rates second in popular usage for this power transistor.

How about your general purpose plans for the Type 2N242 power transistor? Call your Sylvania representative or write for technical data.

*** VOLTAGE REGULATION**
DC CONVERTER
OSCILLATOR, AMPLIFIER
TRANSISTOR COMPUTER
MAGNETIC CORE DRIVER
SERVO AMPLIFIER
VERTICAL SWEEP OUTPUT
PULSE POWER OUTPUT
HIGH CURRENT SWITCH
RF MODULATOR

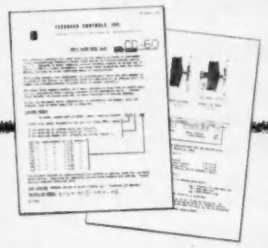


FEEDBACK'S NEW MODEL CD-60 SERIES
SERVO DAMPERS

Now, obtain high velocity and torque constants with good stability in instrument servos without tachometers, networks, or other bench-engineered means of stabilization. With Feedback's new viscous-couple-inertia dampers mounted directly on either end of Diehl FPE-25, 5-watt servomotors, you achieve servo compensation with only the simplest form of servo amplifiers.

Each damper is factory-adjusted to specified time-constants within the range from 0.02 seconds to 1.20 seconds. Three styles of mountings are available: for tapered shafts or straight shafts (with or without integral pinion).

For Complete Application Data — Send For
BULLETIN CD-60



FEEDBACK CONTROLS, INC.
Dept. CE,
899 Main Street
Waltham 54, Mass.

FEEDBACK MANUFACTURES servo instruments for computation and control, gearheads, magnetic amplifiers, ac and dc vacuum-tube amplifiers, viscous-coupled-inertia dampers, quadrature rejectors, synchro-data switches.

SHOPTALK

Coming in May

Two big ones for the control engineer's spring reading creel—

- a complete study of industrial static-switching systems
- the first of a series of comprehensive articles on analysis instrumentation

On static switching

Since the introduction of Cypak systems by Westinghouse Electric Corp. two years ago, static switching has generated many a heated and interesting discussion among industrial control engineers (*What's New*, CtE, Jan. 1957, pp. 26-34). Recognizing the need for clarification and education in this area, CONTROL ENGINEERING went looking for an expert to bring its readers up to date in an unbiased way—unbiased because now GE is in the field, too, and other manufacturers are considering entering it. Our search was over when we located Prof. Robert Mathias of Carnegie Institute of Technology, a PhD with research experience in magnetics, a practical knowledge of the design of static-switching systems, and an avid interest in the field. Working closely with CtE editors, and with the manufacturers and users of static switching devices, Bob amassed a tremendous amount of data which he shook down into the 28-page special insert appearing next month. In it he reviews basic logic and the fundamentals of magnetic and semiconductor switching devices, provides analytical case studies of a wide variety of applications, gives system design tips, and takes a look at the cost picture. Don't miss it.

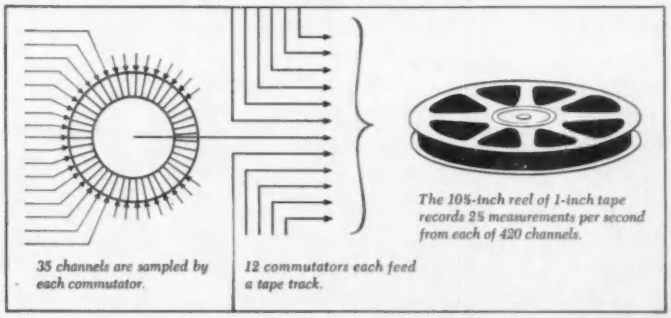
On analysis instrumentation

One large chemical-processing company reports an astounding increase in the use of analysis instruments in recent years. Other users indicate similar trends. They're finding that the only way to maintain efficient and high-quality production is to analyze the process output (often directly in the process stream), determining the material's components and correlating these with measurable and controllable process variables. To keep our readers abreast of this trend, Associate Editor Harry Karp organized a comprehensive 12-article series on analysis instrumentation. The first article comes next month. It will cover the fundamental methods of measurement, some of the math involved in interpreting results, correlation, and automatic process control using analytical instrumentation. The articles to follow will discuss specific methods and equipment: chromatography, nuclear magnetic resonance, ionizing radiation, etc.—valuable contributions to the control engineer's library.

How to record 420 channels of simultaneous data

Boeing Airplane Company's flight tests demonstrate an easy way

Have you ever seen an oscillograph record that was eight and a half feet wide? At fifty channels per foot this is what it would take . . . which shows the decided advantages in the way the Boeing Airplane Company solves the problem. They put 420 channels of data onto a one-inch magnetic tape. Two hours of flight test can be recorded on one 10½-inch reel.



35 channels are sampled by each commutator.

12 commutators each feed a tape track.

The 10½-inch reel of 1-inch tape records 2½ measurements per second from each of 420 channels.

In a published article, Mr. Arthur T. Snyder of Boeing describes their system as a low level, low-speed, pulse-width-modulation technique. It time-multiplexes 35 channels of data onto each of 12 tracks (of 14) on an Ampex 814 Airborne Magnetic Recorder; ($35 \times 12 = 420$). The system inputs are variable resistances, thermocouples, strain-gage bridges and other bridge-type transducers. Each is fed to a segment on one of twelve rotating commutators that sample every channel 2½ times per second. The Ampex 814 recorder running at 3¾ in/sec. records over 8-million measurements in two hours.

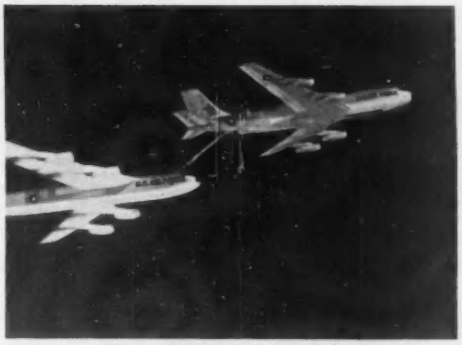
This recording system used by Boeing is limited *by choice* to data that changes at a slow rate. This is by no means a fixed limitation. Certain Ampex recorders (Series 800, FR-100 and FR-1100) have interchangeable amplifiers. Each track can thus be used with any one of three types of recording according to frequency requirements:

With PWM recording (like the Boeing example) as many as 88 channels of low-frequency data can be put onto one track.

With direct recording up to 18 channels of RDB subcarrier data of varying frequency requirements can go onto one track – or very high-frequency data uses one track per channel.

With FM carrier recording one channel of data occupies one track and provides high instantaneous amplitude accuracy. FM is particularly suitable for shock and vibration records.

When a recording containing a large number of channels of data is reproduced, another of magnetic tape's advantages becomes apparent. The data can be reproduced in electrical form. Consequently it is a relatively simple matter to unscramble the channels by automatic or semi-automatic means. Any combination of channels can be scanned, correlated and fed to computing devices. These fortunate faculties of magnetic tape help reduce the handling of vast amounts of data down to a task of wieldy size. For example in the Boeing flight tests already mentioned, all data is published within two or three days after the test instead of from several weeks to several months later as by previous methods.

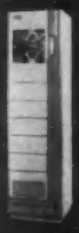


Boeing KC-135 tanker in flight.

If you have a specific problem involving large amounts of data or unusual combinations, Ampex's application engineers will be pleased to furnish further information. More of the capabilities of magnetic tape will be discussed in this continuing series of bulletins. Would you like to have copies mailed direct? If so, write Dept. HH-3103

MAGNETIC TAPE APPLICATIONS BY AMPEX

2











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FEEDBACK

Article triggers Digger query

To the Editor—

We are anxious to obtain the instrument manufacturers' bulletins adapted for training at Carbide & Carbon and referred to in Table I, page 67, of the December 1956 Control Engineering in the article, "How Two Companies Train Technicians". Please supply us with the addresses of:

Barton Instruments Corp. (for Flow Meters Bulletin 11C4)

Mason Neilan (for Liquid Level Controller Series 12,000 Bulletin)

Moore Products Co. (for High Pressure Differential Pressure Transmitter Bulletin 1101)

University of Queensland
Brisbane, Australia

We suggest that you write to the Director of Publications at each of these addresses:

Barton Instrument Corp., 580 Monterey Pass Rd., Monterey Park, Calif.

Mason-Neilan Div., Worthington Corp., 63 Nahatan St., Norwood, Mass.

Moore Products Co., H & Lycoming Sts., Philadelphia 24, Pa.

For lower subscription rate.

To the Editor—

My question is aimed toward a point of policy which demands the attention of the senior editorial staff.

Briefly, the problem is as follows. I am fully aware of the economic reasoning which prescribes that your magazine should sell for a considerably higher price abroad than here. Obviously, $5 for a three-year subscription covers far less than the actual publication cost. However, the foreign rate seems to me to be extremely elevated. I had the privilege of working for the Societe d'Electronique & Automatisme, in Paris, for about 17 months, and am aware that your magazine can only be considered a necessary text, practically a bible, for many engineers there. Since advertisers presumably pay the bulk of your editorial costs, it seems to me that a company which, despite the prohibitive customs duties and long delays to buy needed American products, patronizes your advertisers, should be considered somewhat an exception to the rule-of-thumb that advertising is directed toward domestic consumers. In glancing through the advertisers' list in the January issue, I can point out that SEA employs products, in not insignificant quantities, manufactured by Amphenol, CBS-Hytron, Doelcam, Ford Instrument, Giannini, Hewlett-Packard, Du Mont, Kearfott, Librascope, Potter Instrument, Raytheon, Reeves, and Transitron. In addition, they use instruments manufactured under license from General Radio, Sola, GE, and others. I suspect this vendor list represents as great a cross-section as would that of many American customers, and I can assure you that Control Engineering has been instrumental in many cases toward the decision to employ American equipment, despite the red-tape and expense.

What's the answer?

Robert W. Reichard
Cambridge, Mass.

Control engineering knows no international boundaries. Therefore, your question of increasing the volume of foreign circulation and decreasing its subscription rate is an interesting and appropriate one. Letters such as yours and notes from American control engineers traveling in Europe make it clear that our magazine is much sought after abroad, particularly in Europe. We are striving to meet that demand, and at the same time, to balance the basic equation of a successful publishing enterprise:

$\int$(unique editorial service) $dt = \int$(quality circulation)dt = unique advertising opportunity

In such countries as France we must assess the quality of potential circulation in terms of application engineering practices and in terms of ability to buy the products of our American manufacturers. If your friends can show us quality in those terms, leave the rest to us. Ed.

Greek broadside slays us

To the Editor—

Being closely associated with data reduction and allied fields, I have read Control Engineering with great interest for some time. Being also a one-time student of Greek, I was surprised to note in your January issue an advertisement for Clare Relays on page 23 which purports to quote Archimedes' classic "Eureka", or "I have found it". The ad, however, spelled the word, in Greek characters,

convert to digital recording

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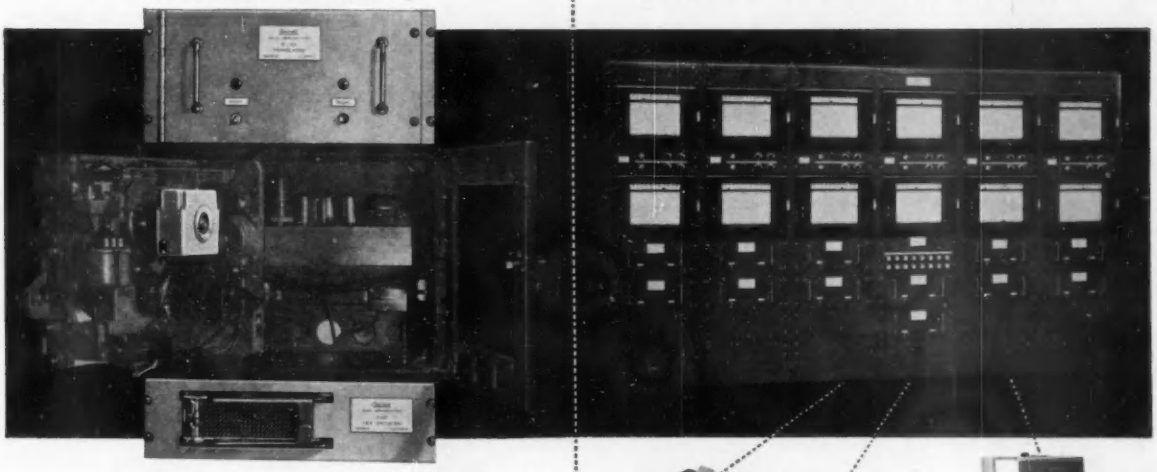
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ECONOMICALLY

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COMPLETE MULTI-CHANNEL SYSTEMS FOR: WIND TUNNEL TESTING; PROCESS LOGGING; ENGINE TEST FACILITIES, ETC.



Equip self-balancing potentiometers of any standard make with DATEX single channel kit. No special gearing, modification, or complex brackets required. Used by leading recorder manufacturers for digital recording.

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Giannini digital data handling and recording systems can be adapted to many processes that require rapid and/or continuous recording of precise information.

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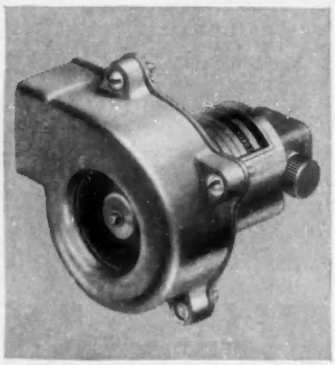
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Dept. P, 1848 Rock Street, Rockford, Illinois

FEEDBACK

as "CHEURIKA" (which I quote in Roman characters, not having a Greek typewriter), with the translation, "It is found". While the point may not be important as far as the ad is concerned, it struck me immediately, and I take the liberty of pointing it out to you, as probably others have already done.

F. P. Morrison
Commander, U.S.N.
Point Mugu, Calif.

If 'twere Latin, we might attempt return fire. We can only withdraw before the superior fire-power of a Greek-reading commander and wonder if it was good after he found it. Ed.

Tape-sorter opponent speaks

TO THE EDITOR—

The article entitled "How the Four-Tape Sorter Simplifies Storage", appearing in the February 1957 issue of CONTROL ENGINEERING, was obviously a tutorial paper on the subject of tape sorters. Indeed it succeeded very admirably in presenting most pros of the specialized tape sorters offered as part of several commercially available computer systems. However, it was not the entire story and I believe that "the consumer", student, and other interested parties are entitled to the full story. Then they may judge for themselves the merits of a specialized tape sorter versus the use of a general-purpose computer.

To accomplish this end I submit the following additional material.

The four-tape sorter provides a specialized computer designed to perform certain tape-processing functions common to tape-operated computing systems. It is reasoned that tape functions such as sorting are relatively simple and hence should not be used to occupy the time of an expensive general-purpose computer. Thus, several computing systems have been provided with specialized tape sorters at about ½ to ¼ of the cost of their general-purpose computer. This would seem to be an ideal solution. That is, buy an inexpensive specialized device for relatively simple tape-sorting operations.

Cost analysis aids in comparison

Consider more carefully the economics involved. Where an installation has less than a total of eight hours processing per day, including sorting, the rental of a single general-purpose computer, which is always for a minimum of eight hours, handles all requirements. In the case of a purchased machine the economics of actual equipment depreciation (proportional to hours of use), servicing and maintaining a parts inventory for one versus two machines, maintaining an operating personnel group, etc., also dictate the use of a single general-purpose machine.

Where the combined requirement of sorting and other computing exceeds one shift of time (normally eight hours), the general-purpose computer on rental only costs 50 percent of the stated rental. Thus, any time savings from the general-purpose computer by acquiring a tape sorter will first reduce costs from the second shift and at only half of the basic computer rental costs. Since the tape sorter costs approximately one-half of the computer rental there would seem to be no great economic savings possible. In addition, time beyond the first shift is normally billed on a prorated basis, that is, by actual use. Therefore, only the savings of a full second-shift use of a general-purpose computer for sorting would realize any savings, if at all.

In the case of a purchased computer with more than one shift of use, the cost of personnel overtime and maintenance for a single computer is usually less than the requirements of maintaining two different types of machines (spare parts, service know-how, etc.). However, this may not be a clear-cut case and a potential user should base his decision on the individual requirements of his installation.

Analysis of sorting time helps too

All of the preceding is true even if it is assumed that the general-purpose computer and specialized tape sorter take the same amount of time to perform a tape-sorting operation. As a matter of fact, the general-purpose computer has available to it techniques that will allow it to perform sorting faster than a specialized tape sorter. These general-purpose computer-sorting techniques may be categorized as:

(1) Tape-record blocking:

As the author noted, a tape sorter is limited by tape-passing speed. Since tape sorters do *not* have an internal memory for holding tape records, each tape record must be written on tape with its own start-stop, inter-record gap. (This lack of memory should not be confused with the memory pro-

vided in tape sorters for holding data to be used for making output-tape-selection decisions based on the sort "key" recorded as a part of each record.)

In a general-purpose computer, tape records may be "blocked". That is, several records may be recorded with a single inter-record start-stop gap. When the block of records is within the computer memory the program can select the sort key from each record. Consider, for example, a sort involving 100 character records. With a density of 200 characters to the inch, a tape speed of 75 in. per second, and a start-stop time of 100 millisec, the two techniques would have the following tape times per record:

Single record (tape sorter):

10 millisec (start-stop) plus

$$\frac{100 \text{ char} \times \left(\frac{1 \text{ in.}}{200 \text{ char}} \right)}{75 \text{ in. per sec}}$$

= 10 millisec plus 6.7 millisec
= 16.7 millisec per record.

Blocked records (computer):

10 millisec plus

$$\frac{10 \times 100 \text{ char} \times \left(\frac{1 \text{ in.}}{200 \text{ char}} \right)}{75 \text{ in. per sec}}$$

= 10 millisec plus 66.7 msec
= 76.7 millisec for 10 records.
or 7.67 millisec per record.

This is a 54-percent reduction in tape time as a result of tape-record blocking. This also results in a single tape containing many more records for processing by the computer.

(2) Internal sorting

Most computers provide simultaneous tape-reading, internal computation, and tape-writing. This means that a certain amount of internal computation time is available while performing tape operations. A general-purpose computer can be used during the first pass to place large groups of records in ascending sequence before they are written onto tape. This materially reduces the number of passes required. For example, 1,000 records in random order would require at most ($\log_2 n$) passes on a tape sorter. (An extra pass is required sometimes initially to split the records into two tapes for comparison purposes.) This requires a maximum of 10 passes on a tape sorter. The general-purpose computer may, for example, produce ordered sequences of 40 records, in four tape blocks of 10 records each, during the first pass. Then, the general-purpose computer would perform successive two-tape-merge operations, as follows:

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Swing-out design making all components readily accessible in Series 8000 multi-point recorder is demonstrated below. Cover of recorder mechanism removed to show construction.

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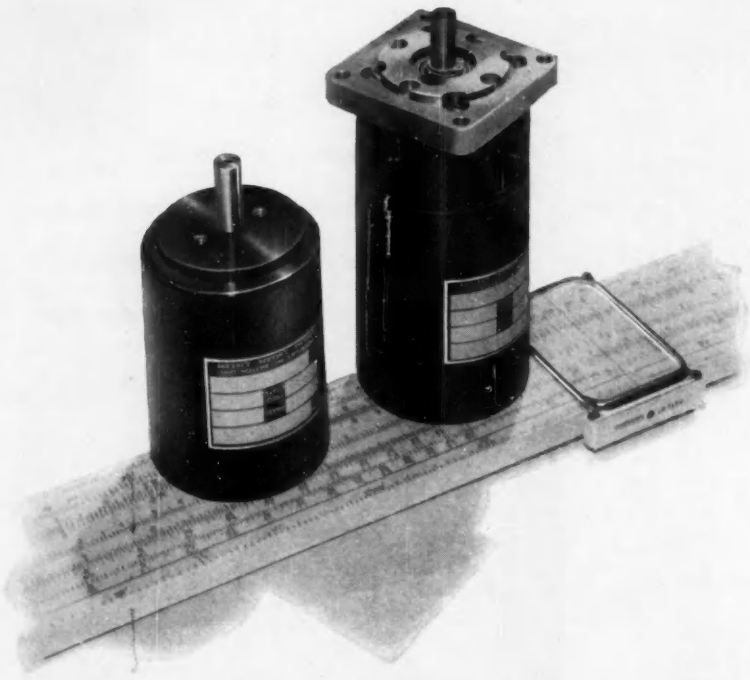
Additional features include: up to six limit switches for high and/or low signal indication, single or multi-color printing, and fast cross-chart speed. Call your nearby Wheelco field engineer today for Bulletin F-7955, or to discuss how these multi-point recorders can improve your processing.

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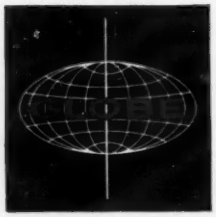
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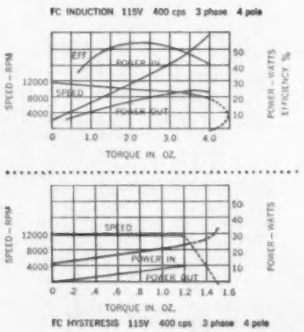
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FEEDBACK

Pass number	*Length of sequences*
1	40
2	80
3	160
4	320
5	640
6	1,280

This is a reduction of 40 percent in the number of passes required by a a general-purpose computer. The use of a three-, four-, or more tape-merge will result in further reduction in the number of passes required by a general-purpose computer.

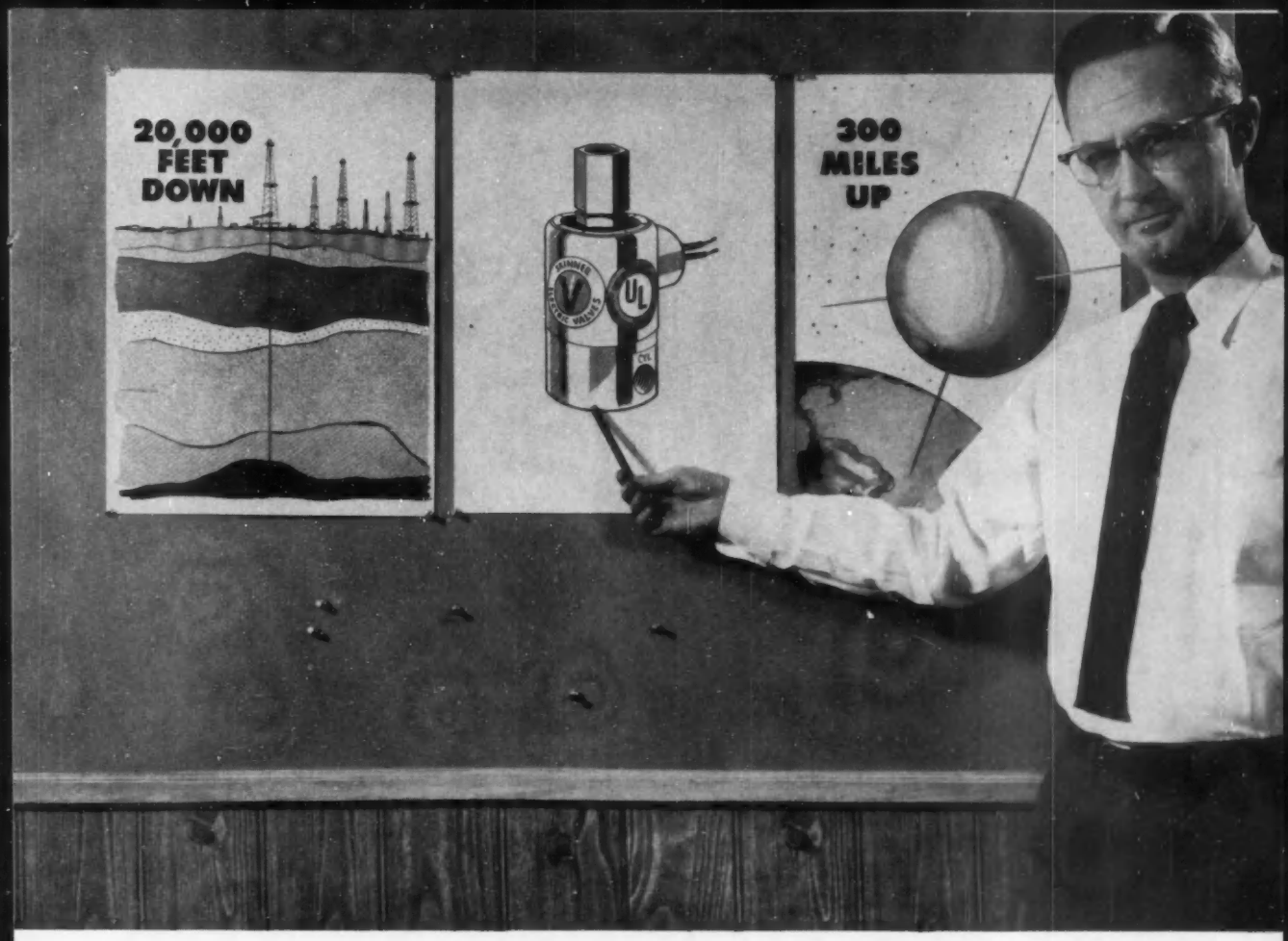
In general, the proper selection of initial length of sequences produced during the first pass can keep the internal processing time required down to the "free" time available while performing tape-reading and writing. This technique, combined with blocking of records, can be used to realize a very large reduction in tape-sorting time on a general-purpose computer as compared to a specialized tape sorter.

Other pros and cons enter the picture

What are some of the other pros and cons of general-purpose computer sorting versus specialized four-tape sorter operations?

(1) With little additional hardware the tape sorter can be made to merge tapes (two at a time), or extract tape data as separate operations. With more hardware and a fifth tape these two functions can be combined. In a single run, a master-file tape may have active records extracted for computer processing while merging modified master records from a previous computer processing run. However, these operations can also be performed on a general-purpose computer simultaneously with other computer processing and with little or no added running time. This results from the fact that a computer has the ability to handle several input tapes. In addition, the general-purpose computer can superimpose accounting controls on the tape operations. These include record counts, control totals, and printed registers of file changes.

(2) A specialized tape sorter can extract active records for processing by a computer. Inactive records need not be processed by the computer. The general-purpose computer would, in most cases, have to read in all master records, active and inactive. However, the availability of accounting controls, tape-reel labels, and other readily available general-purpose com-



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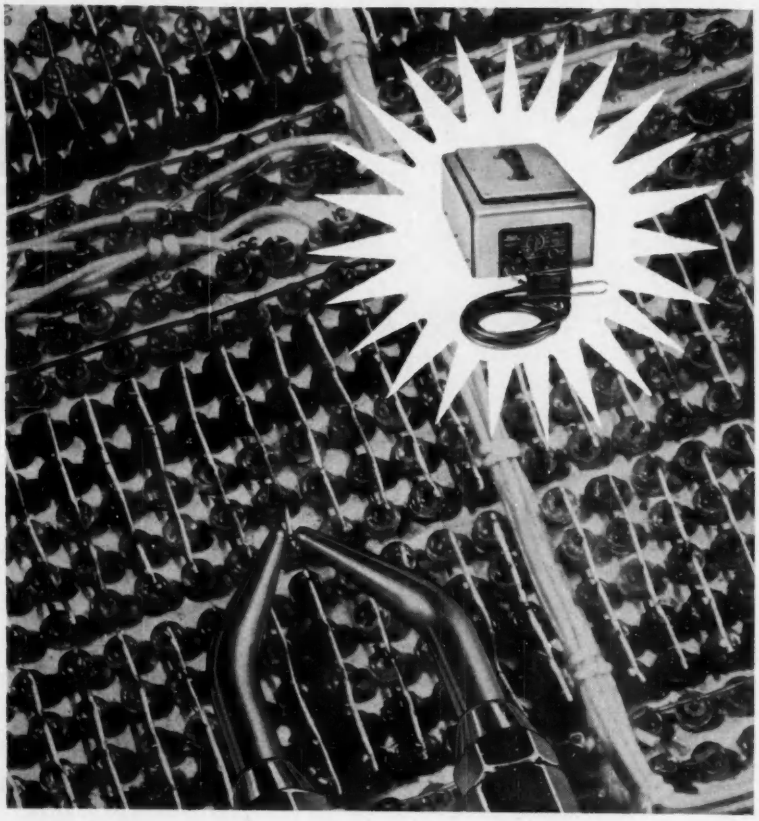
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Weldmatic welding packs 94.5 components per cubic inch in this experimental matrix by Hughes*

Hughes achieved the unprecedented compactness of this computer matrix by making diode connections *right next to the diode body*... with a Weldmatic stored-energy welder. Note how tweezer handpiece simplifies working in hard-to-reach locations. Weldmatic instantaneous precision welding, which also makes joints more reliable and uniform, may offer advanced solutions to *your* metal-joining problems, too.

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Weldmatic literature and a full technical report of the Hughes miniaturization techniques referred to above are available on request.

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FEEDBACK

puter programming abilities allows direct, positive control of all tape files. Thus the record counts, control totals, and printed registers available from a general-purpose computer give complete control over machine performance, human operator "interference", and other possible sources of system error.

There are some instances in which the availability of a specialized tape sorter is good. Where cost is secondary, lack of complete control is tolerable, and the problem requires more than one full shift of general-purpose computer time, the sorter should be considered. However, the user must weigh all of the factors involved in determining his choice.

Jerome Svigals
San Jose, Calif.

The opposition presents a good case, although his last paragraph is a bit dogmatic. Any rebuttal before the two debaters sum up? Ed.

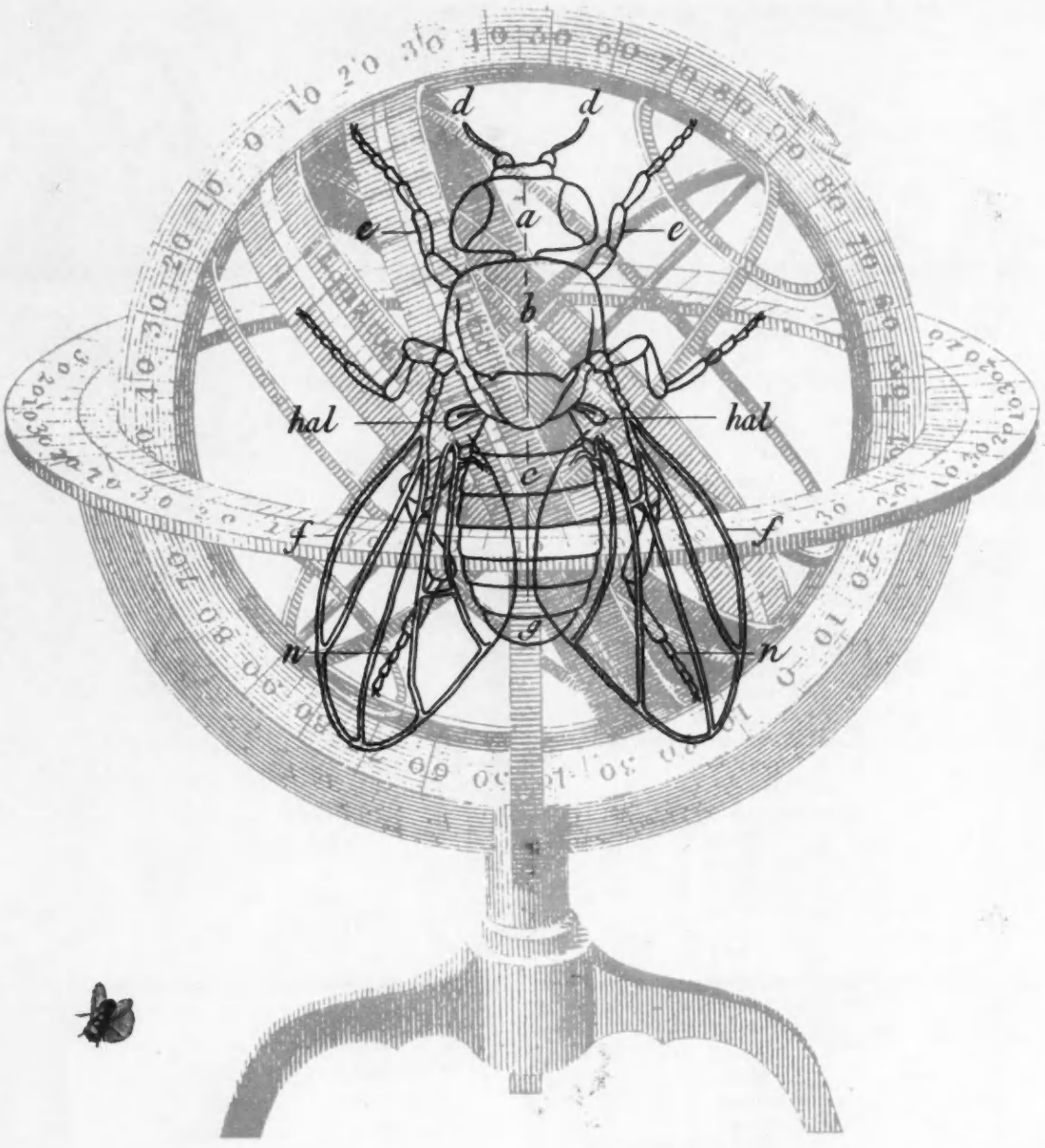
A captain for every team

To the Editor—

The article, "A Trainer for Chemical Process Operators", Dec. 1956 issue, describing the use of analog simulation for the training of chemical process operators, reported the work of several engineers. J. P. Laird wrote the material but disclaims much of the credit for the success of this technique. As you can readily appreciate, very few engineering accomplishments can be accredited to a single individual. In this case, Laird had the original idea of applying techniques, which he learned in the U. S. Navy for training aircraft pilots, to the chemical industry problem of training process operators. The trainer he visualized incorporated relatively complex and expensive analog computer components in order that the reaction to a change would be displayed in much the same fashion as it would actually occur in the process. H. O. Hite, another instrument engineer, took this idea and sold the plant people on a practical, low-cost version. The article described the result. The equipment was built by, and incorporated many of the ideas of, Ed Carmody, a builder of simulators in Buffalo, N. Y. Additionally, the plant people for whom the job was done contributed numerous ideas to make the trainer useful and adequate.

J. Johnson Jr.
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HANS R. FRIEDRICH **puts wings on systems**

The groups that are designing the Atlas missile are organized into systems just as complete as the systems that control and guide it. The reason: the boss really believes in systems engineering.

Systems-minded chief of the Flight Mechanics Section at Convair's new Astronautics Div. is Dr. Hans R. Friedrich, a veteran missile builder who got his technical baptism at Peenemuende, the birthplace of the German V-2 rocket. That exposure was impressive enough to change his life work from research in molecular physics to design of automatic-control systems.

Friedrich's entrance into the field of automatic control had all the drama of an Eric Ambler thriller. He was a physicist at the Berlin research institute of the German General Electric Co. in 1939 when he read in a newspaper that the German High Command was looking for a specially qualified scientist, a man fully trained in experimental physics as well as in mathematics. The assignment: take over a major problem area in a completely novel research program under way at an isolated spot along the Baltic Coast. Inborn curiosity prompted Friedrich to apply for the job. His interview took place in an inconspicuous Berlin restaurant; it lasted several hours and resembled a stiff doctoral examination rather than a job interview. At the end, the interviewer—whose name remained a secret—handed Friedrich prepared tickets and travel papers to Zinnowitz on the Baltic island of Usedom.

In a week, Friedrich was living in a fenced-off proving ground of the German army in the northwest corner of the island. This place and what he saw there changed his professional life within a matter of hours. The place was, of course, Peenemuende, and the things he saw were the embryonic stages of the fabulous V-2 rocket. Three months later, Friedrich joined the staff of Wernher von Braun. His assignment was made more specific: he was to develop—first on a purely mathematical basis, later on a hardware basis, and then on a flight-test basis—the automatic-control system for the Aggregate 4 (A4) (the code for the V-2 project). The success of this weapon established Friedrich as one of the world's experts in control engineering.

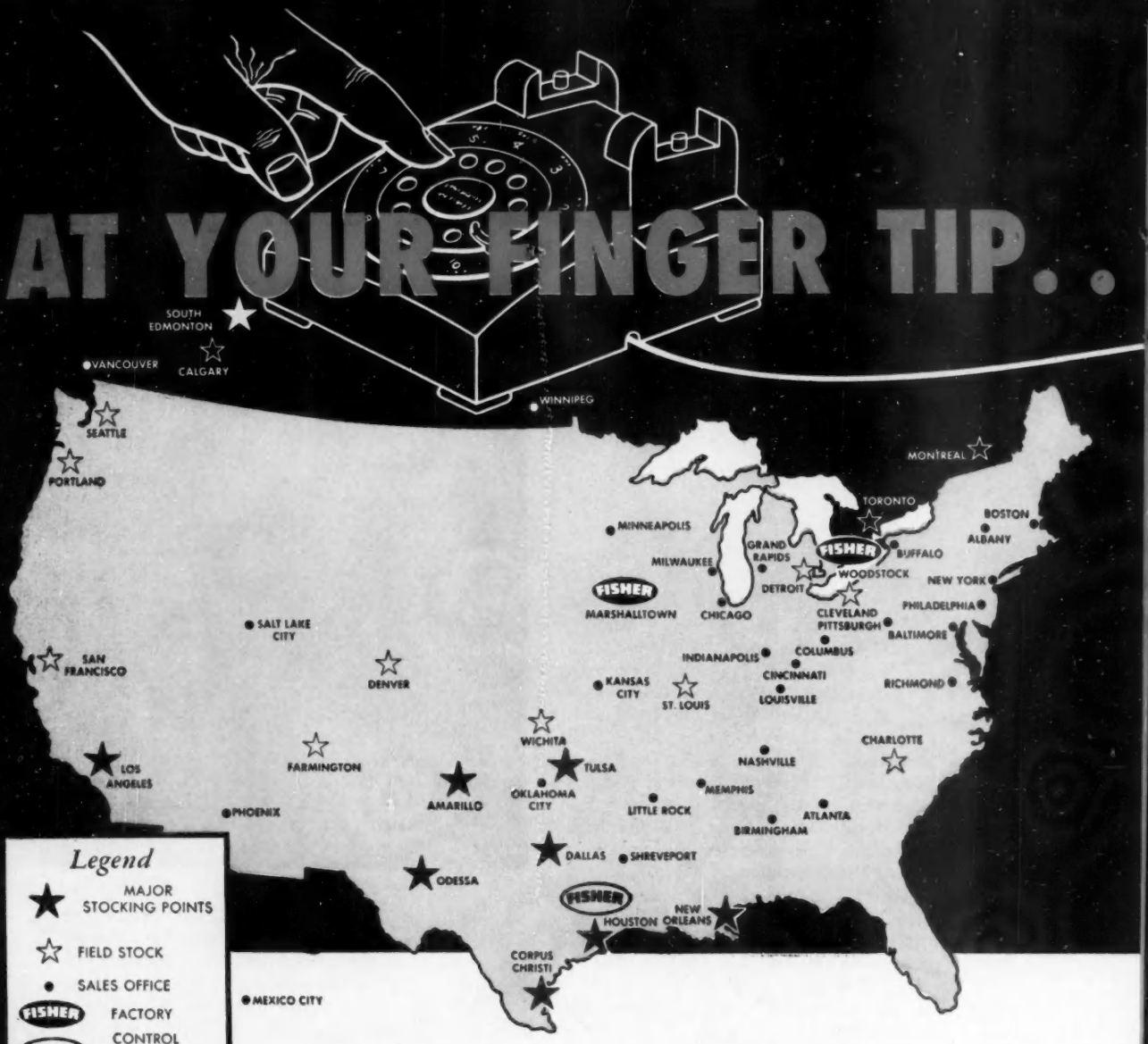
In 1945 Hans Friedrich was invited by the U. S. Army, along with more than 100 other scientists, to join the rocketry research programs being carried on in the U. S. For four years, he was stationed at Fort Bliss, Tex., working on various Army guided-missile projects. Then he spent over a year at the Redstone Arsenal, again concentrating on his specialty: flight mechanics, including trajectory studies.

For reasons of health, Friedrich moved his family to Southern California in 1951. In August he joined the San Diego Div. of Convair as a design specialist in charge of all structural and control dynamic work in missile programs. And, in December 1955, he moved to the then-new Astronautics Div. where he was appointed chief flight mechanics engineer. Earlier that year he had become a naturalized U. S. citizen.



Today Hans Friedrich's target is the conquest of space. His section's work in missile development covers: dynamics, servomechanisms, flight performance and analysis, data processing and flight simulation, and computers. His professional activities have carried him to the position of executive director of the San Diego Section of the American Rocket Society; he is also an associate fellow of the Institute of Aeronautical Sciences, and a visiting professor of engineering at the San Diego extension of UCLA.

Outside the laboratory, Friedrich continues his systems concept in the pursuit of two hobbies: reading and music. His wife and two daughters are content to sit back and enjoy the music from the Friedrichs' hi-fi set, letting the systems expert handle the design and construction of the components. But even when he's relaxing, Hans Friedrich's mind is alert—for as a scientist, he knows that in these tension-free moments he may be most receptive to the answer to a knotty problem in automatic guidance.



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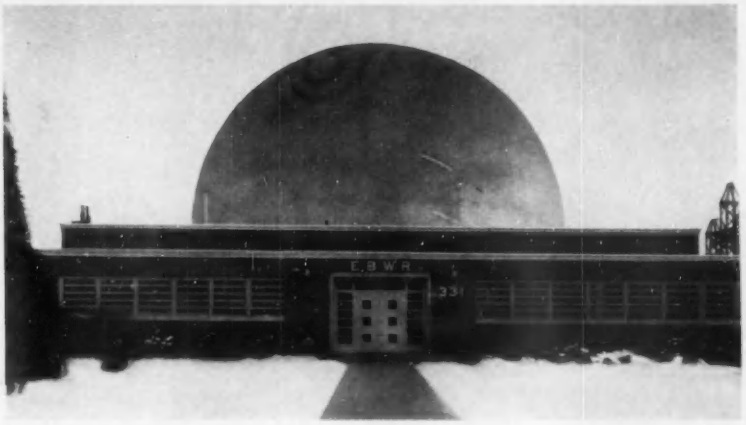
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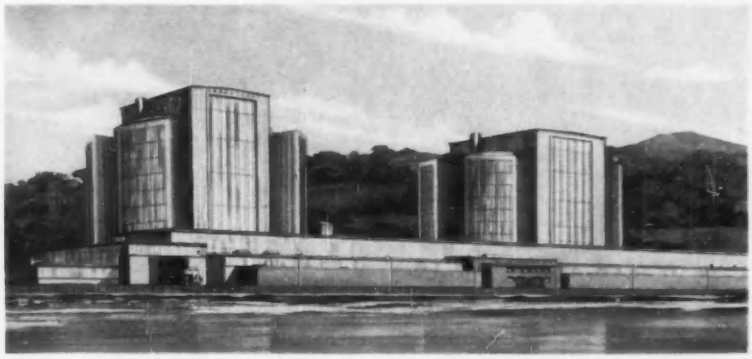
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New Nuclear Power Plants Shun Feedback Control Systems

OPERATING . . .

at Argonne National Laboratory, 5,000-kw experimental boiling-water reactor officially went on line in February ceremonies.





PLANNED . . .

for Hunterston, Scotland, this 320,000-kw plant will use two gas-cooled reactors to supply steam to 6 turbo-generators (p 27).

But remote controls and instrumentation still represent up to 25 percent of the total cost of A-power plants.

Automatic feedback control systems for nuclear power plants are still a long way off. That's the opinion of engineers who designed the instrumentation and control for the Experimental Boiling-Water Reactor (EBWR) plant at Argonne National Laboratory.

The 5,000-kw EBWR officially went on line in February after ceremonies marking it as the first U.S. atomic power plant built solely for the purpose of generating electricity. Besides supplying most of Argonne's electric power requirements, the plant will produce the kind of boiling-water reactor data that can only be provided by a working installation.

And EBWR presents control engineers with a preview of what the next few years will bring in the way of atomic power plant controls as more pioneering projects are completed.

Two major characteristics stick out:

- Maximum use of remote controls, frequently manually operated.
- Minimum use of complete automatic-control systems.

Argonne control specialist J. M. Harrer, who supervised the design of EBWR's instrumentation, cites three reasons for this:

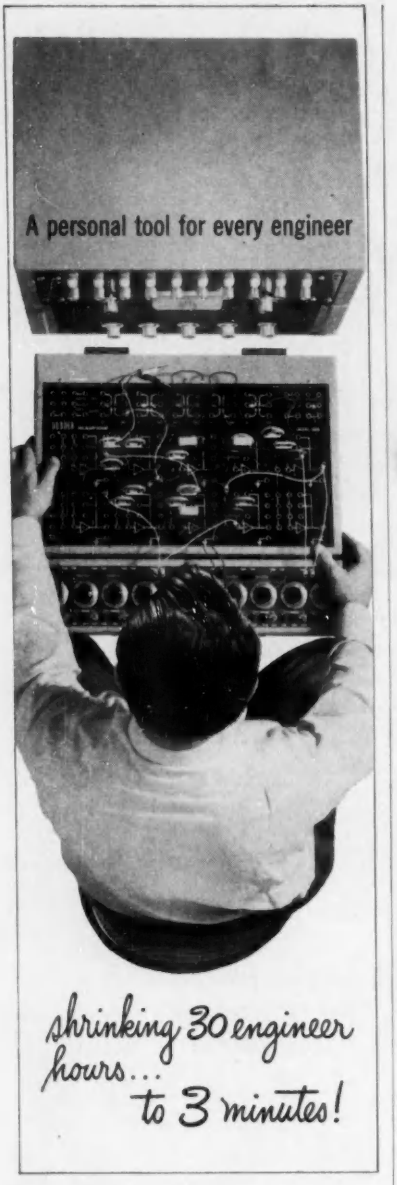
1) power-reactor technology is still so new that plant designs proposed at the start of a project are changed radically as the project progresses;

2) at the present stage of technology, emphasis is still being put on the reactor itself—reactor physics, fuel-element technology, and heat transfer;

3) nuclear-power plants are tremendously expensive because of their newness; the added expense of completely automatic controls is not warranted.

Harrer explains it this way: "The reactor engineer does what he has to do, then he comes to us and says, How do I control it? Sure, control is important, but at this stage it's not one of the determining factors in reactor plant design."

Support. There's some concrete evidence to support this view. Just last

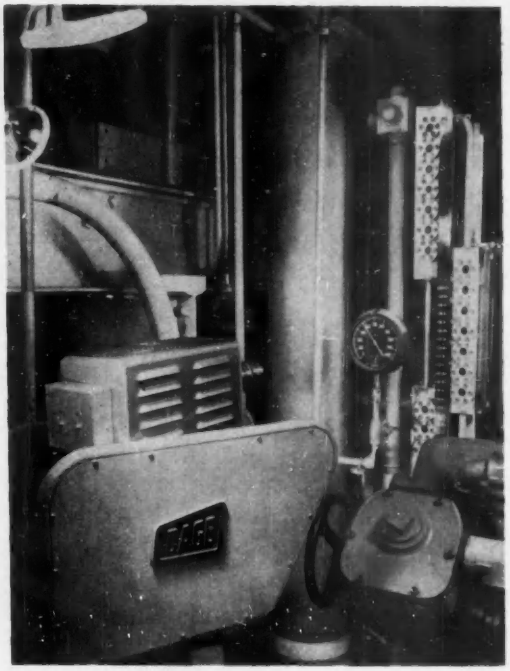


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month, Britain's Atomic Energy Authority admitted that some unexpected technical problems with fuel elements had developed after the Calder Hall atomic power station went on line in October 1956. According to Managing Director Sir Christopher Hinton, "It's nothing that a little engineering can't fix." But unexpected problems in the reactor make A-plant designers shy away from automatic-control systems.

British views on the use of automatic controls are not too widely divergent from the Argonne opinion. Needing additional electric power generating capacity critically, the British are pressing the development of big atomic-power plants. Typical of the philosophy is the proposed control system for a 320,000-kw gas-cooled reactor plant which G. E. C. Simon Carver Atomic Energy Group will build for the South of Scotland Electricity Board (see page 27). R. G. Smith, chief electric engineer, reports a minimum use of automatic controls in the plans drawn up for the Hunterston station.

Boiling water reactors

A look at the instrumentation of the EBWR shows how the remote-control philosophy is carried out. The boiling-water reactor is one of five types being developed under the Atomic Energy Commission's power-reactor development program. It differs from the pressurized water reactor powering the submarine *Nautilus* in that steam is generated right in the pressure vessel, and collected over the uranium-fueled core.

Self-regulation. The direct cycle does away with the heat exchanger for generating steam. But advocates of the boiling-water reactor claim its big advantage lies in its self-regulation. If reactivity is added to a boiling reactor, by withdrawing a control rod, for example, the heat-generation rate increases only to a point where the reactivity subtracted by steam bubbles exactly compensates the reactivity added by the control-rod withdrawal.

This negative reactivity effect of steam bubbles makes the boiling-water reactor easier to control than other types. It stems from the action of the steam bubbles forcing the water moderator out from between the fuel plates, thus allowing neutrons to escape before fission can result. Argonne engineers claim that the boiling-water reactor power level responds to control-rod withdrawal the same way the power output of an automobile is increased by depressing the accelerator a desired amount.

Only rod movement is used in EBWR to control power level. There's no attempt to change power level by varying coolant flow or steam flow.

Remote controls. The entire EBWR facility, steam plant as well as reactor, is operated by remote control. Argonne designers estimate that the cost of instrumentation and control in a boiling water reactor plant will represent about 25 percent of the total

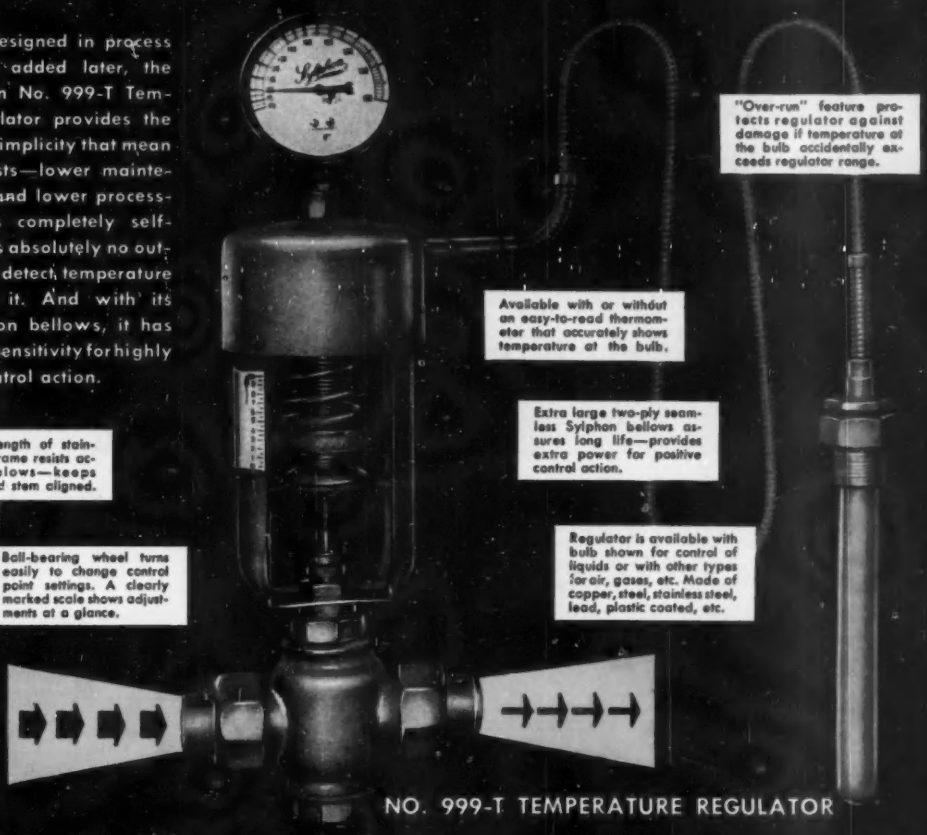
(*Continued on page 190*)

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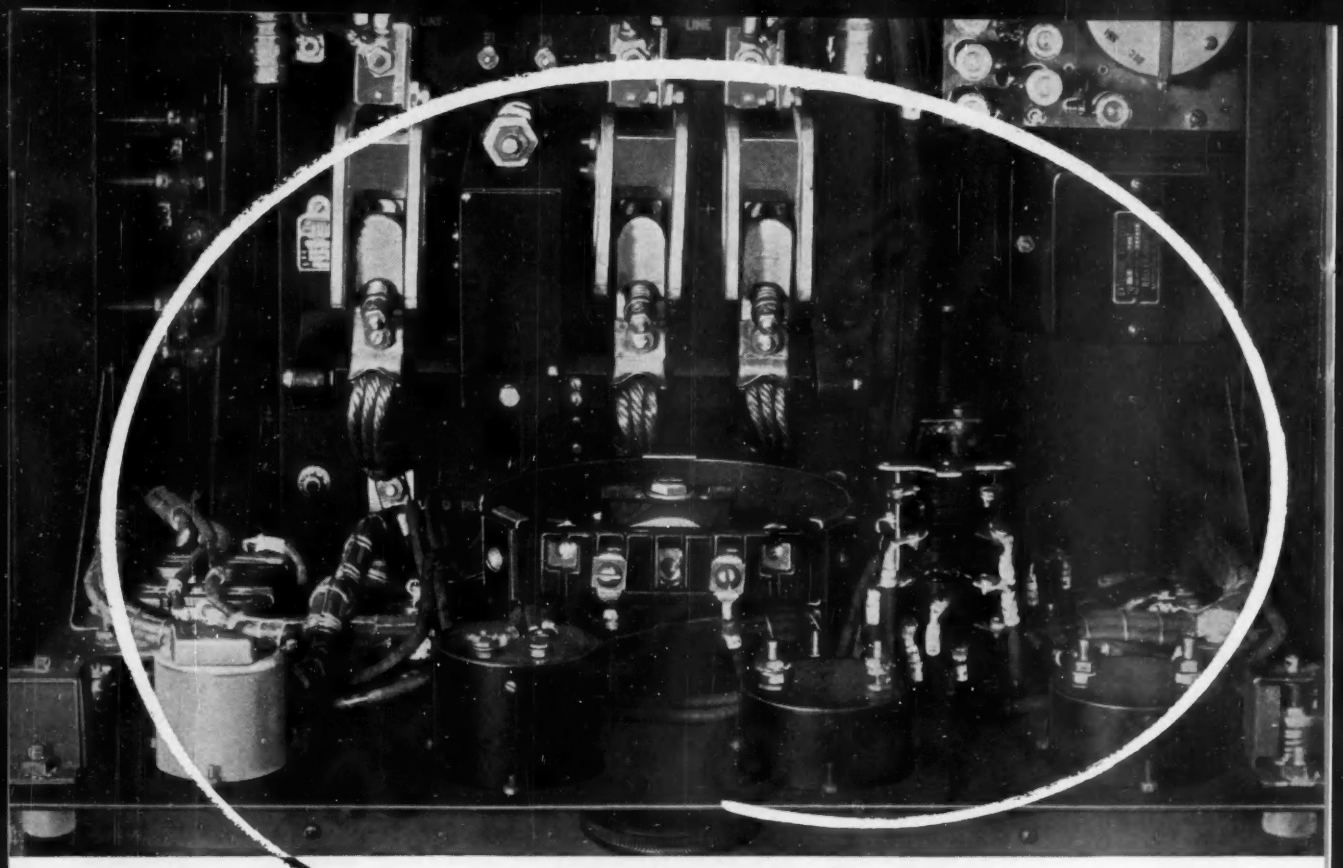
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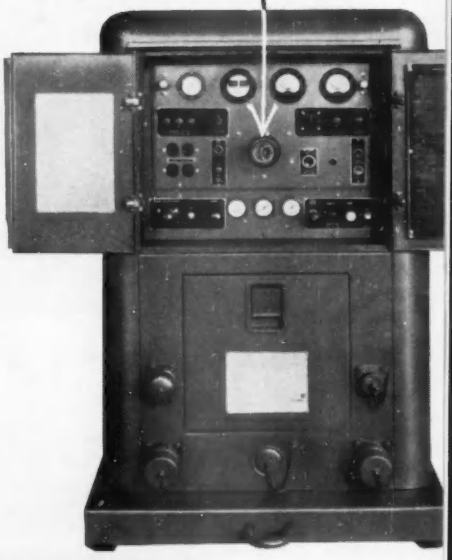
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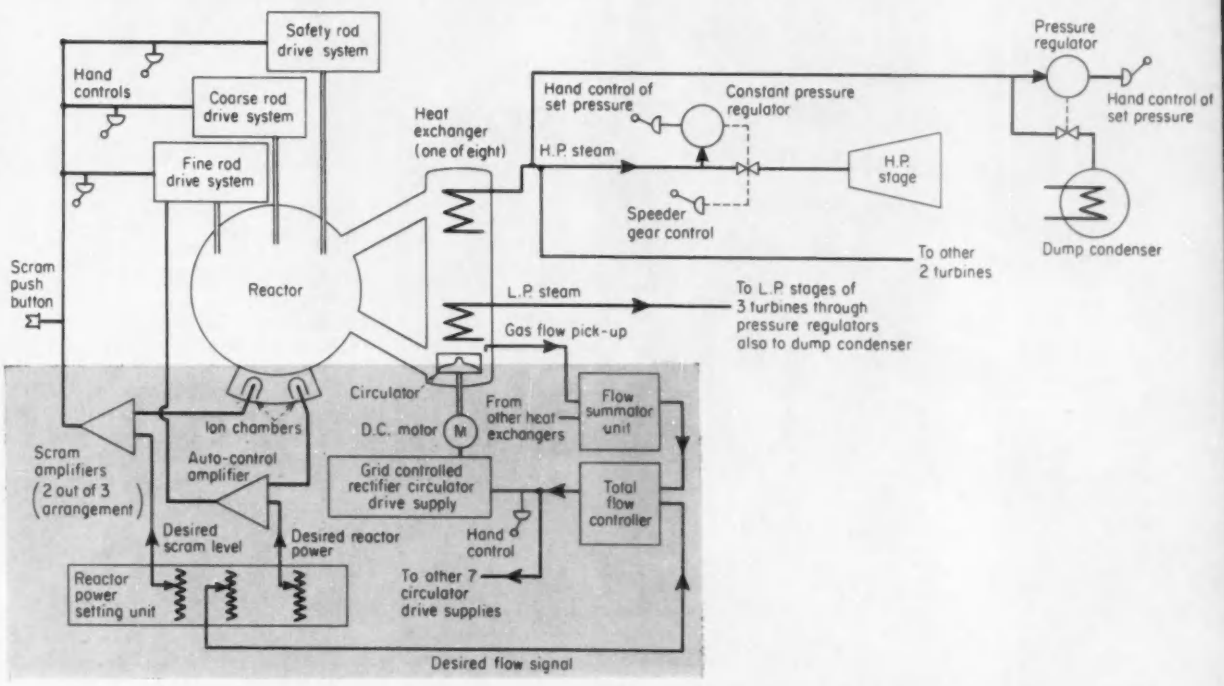


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British Plan Two-Reactor Power Plant

Here is a preview of the proposed control system for the 320,000-kw Hunterston Atomic Power Station, biggest A-power plant project announced so far by the United Kingdom.

R. J. SMITH
Chief Electrical Engineer
G.E.C. Simon Carver
Atomic Energy Group

South of Scotland Electricity Board has approved plans for a 320,000-kw atomic power generating station to be built at Hunterston, Scotland. The big central station will be powered by two gas-cooled reactors. The control system for the station has been designed with two primary requirements in mind: load-changing with small temperature shifts, and continuous operation during partial coolant failures and reactivity changes inherent in on-load maintenance and manipulation.

Plant design. Heart of the station will be two natural-uranium-fuelled reactors, moderated by graphite and cooled by carbon-dioxide gas. Eight heat exchangers operating in parallel serve each reactor, producing steam for three 60,000-kw turbo alternators. A steam interconnection is provided between the two halves of the station. Normally this is closed; each half operates with its own trio of turbine generators.

At the base of each heat-exchanger pressure vessel there is a vertically mounted centrifugal impeller to circulate the coolant gas. Each impeller is powered by a 2,000-hp motor.

One unique feature proposed for the plant is an arrangement for changing fuel elements while the reactor is on-load. This is to be accomplished by coupling a pressurized charge and discharge machine to the bottom standpipes of the pressure vessel.

Control arrangements. A central control room houses all main plant controls. The room is divided into two parts, with the instrumentation for each reactor kept separate. The most important controls and instruments associated with each reactor and its plant are mounted on a control desk. Other instruments and controls, featuring mimic diagram technique, are mounted on panels.

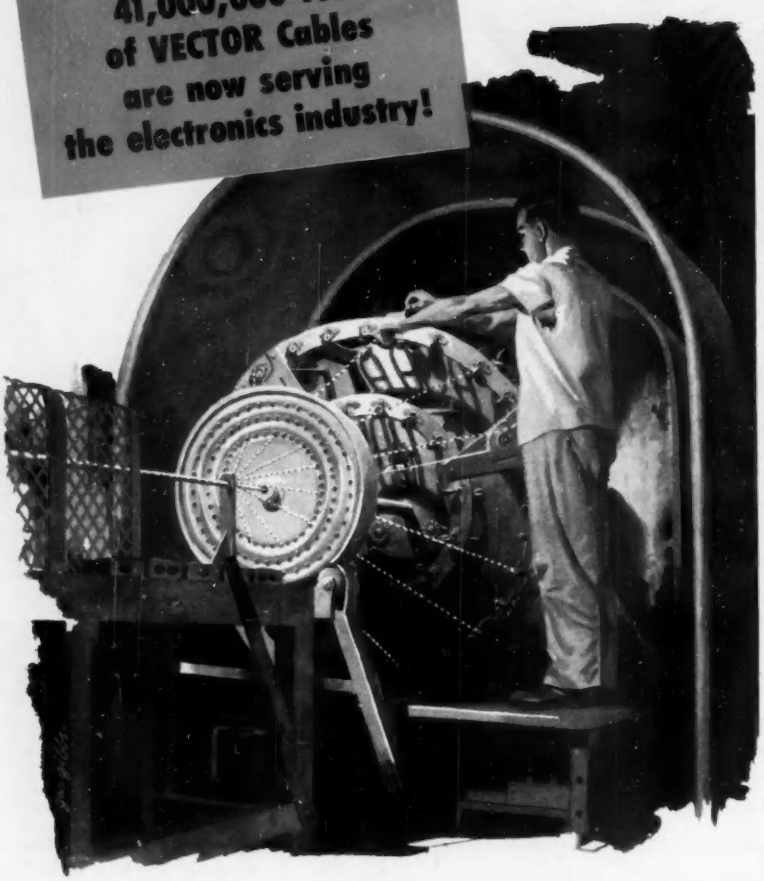
Turbines are run up to speed using local gage panels. All other parts of the plant are started up from the control room.

Station output will be set by the



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WHAT'S NEW

"... each control rod has an identical mechanism in top standpipe ..."

power generated in the nuclear reactors. All deliberate load changes will be initiated by movement of control rods. Overall control involves coordinated variation in neutron flux, coolant mass flow, and steam flow. For the range 25 to 100 percent full power, coordination will be achieved with a one-knob adjustment.

The changed flow of coolant associated with a deliberate change in reactor power level results in a changed heat flow from coolant to water and steam in the heat exchangers. Steam pressures are thus affected, and pressure regulators associated with the inlet valves to each turbine automatically adjust the steam flow to maintain constant pressure conditions. Each heat exchanger has a simple form of automatic feedwater control operating from drum level.

The dump condenser capacity is insufficient to absorb the excess steam produced when a turbo-alternator trips out, but with the control system provided, it is possible, for example, to make an effective controlled reduction in reactor power from 100 to 33⅓ percent in under 30 min.

In the shut-down state, control of the reactor and coolant circulators is entirely manual. As long as fission product heating is significant, it is based on maintaining suitable temperatures in the coolant circuit. Only two heat exchangers per reactor are then in operation; generated steam is passed to the dump condenser.

Reactor control components. Control of the neutron flux is affected in a conventional manner by boron rods, each of which is controlled by a mechanism mounted in the top standpipe.

The 156 rods are divided into four groups: two for course control, one for safety, and one for fine control. Interlocks prevent the withdrawal of more than one group at a time (other than the two coarse-control groups).

The mechanism for each control rod is the same—each uses a wire rope and winding drum. A driving motor with a permanent magnet rotor is mounted in each control-rod standpipe, and is supplied with low-frequency ac from an induction regulator, uniquely connected with transformers and rectifiers. The permanent magnet motor moves the rods in and

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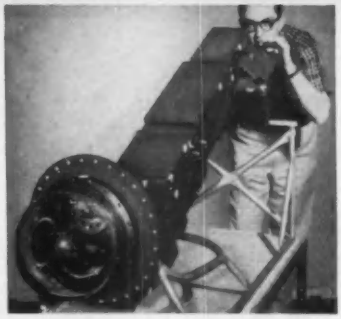


He's getting new basic knowledge on properties of semi-conductors

Here Dr. Rolf K. Mueller determines electrical properties of a semi-conductor specimen having a low angle grain boundary. He and his colleagues in the Electron Physics Laboratory of the Mechanical Division of General Mills grow their own pure specimens with carefully oriented crystal structures (germanium in this case). They then mount specimens very precisely for basic research involving the effect on physical properties of varying angles of junction. Variation of the angle of crystal orientation at the junction (the "grain boundary") has a predictable effect on the electrical reactions of the semi-conductor.

Semi-conductor work is but one facet of an integrated program in solid state physics. Studies of chemical, mechanical and surface properties of solid crystals and "sputtering" of metals under ion bombardment are among several other areas presently being researched in the Electron Physics Laboratory.

Some of this research is still basic, but it typifies the advanced and creative work we do. In many fields, this "research for tomorrow" is translated regularly into practical applications for industrial and military use today. If you have product or production problems, possibly you can profit from these applications and from our precision production facilities.



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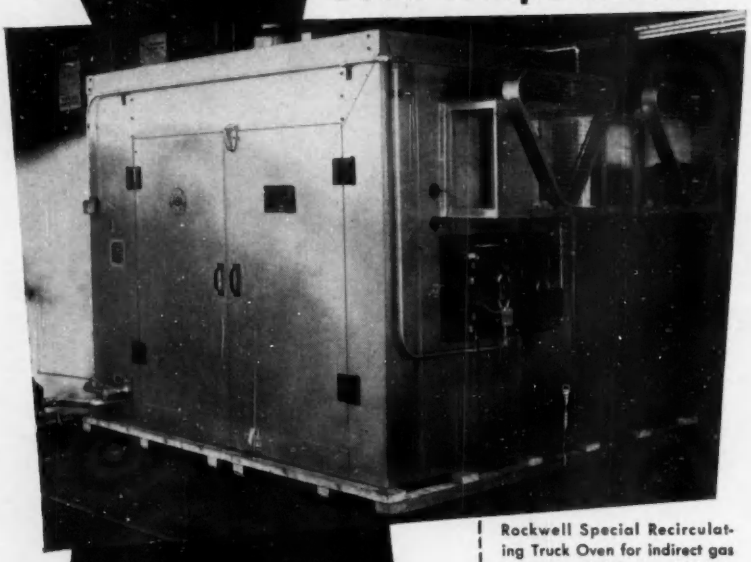
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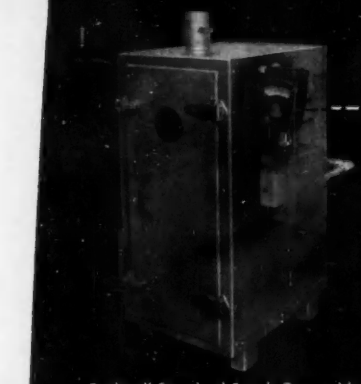
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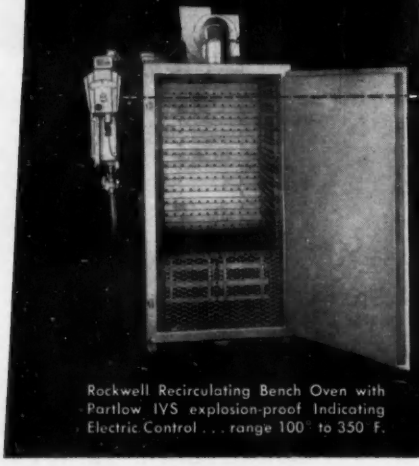
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The rods are tripped into the core during an emergency by removing the supply to the motor. This design, incorporating all these duties in a single machine, eliminates clutches, and brakes within the pressure shell.

Circulator control. The centrifugal impellers which circulate the coolant gas are driven by dc motors because of their wide speed range and inherent efficient operation at all loads. Grid-controlled mercury-arc rectifiers supply each motor. The rectifier output, and hence the speed of the motor, is governed by the phase of the grid voltage, which is adjusted by compensated motor-driven induction regulators. The speed of each circulator determines the coolant mass flow. Each circulator can be individually controlled, but normally a grouped control is used.

Automatic control system. A desired power setting unit containing six gaged potentiometers is mounted on each reactor operator's desk. A small motor with on/off control drives these potentiometers and also a mechanical register indicating the desired power in megawatts. The maximum rate of change of desired power is 5 percent of full power per minute in either direction. But the system can make more rapid decreases in desired power as an alternative to reactor scram under selected fault conditions.

One potentiometer sets desired power as determined by the reactor flux density, another provides a desired flow signal. Three provide trip-level settings for three scram amplifiers, and the sixth potentiometer provides a desired flux setting for an independent metering arrangement showing the difference between desired power setting and the reactor power as measured by an ion chamber. The automatic adjustment of scram amplifier trip-level avoids accidental scramming of the reactor when increasing power while maintaining the scram level near the operating point.

Two separate closed-loop systems maintain the neutron flux and the total

NONLINEAR CONTROL discussed by *Charles Taylor*

It may seem to be inconceivable that nonlinear control can be applied to complex dynamic processes. Excellent examples of such processes are to be found in the petrochemical industry. Paradoxically, however, nonlinear control is implied if optimum control of such processes is desired. Optimum is defined here in the sense that maximum efficiency, or economy, of plant operation be achieved for specified product quality in the face of changing plant conditions.

Even the word nonlinear has a bewildering connotation. If a system is nonlinear it is frequently assumed that the system transcends human understanding or control. To actually apply nonlinear control to a process (linear or nonlinear) seems further out of the question. A basic reason for this awesome stature is the fact that the familiar tools of linear systems design and analysis no longer apply. The principle of superposition (i. e., the sum of effects being simply related to the sum of causes) is not valid in the nonlinear realm. The mathematical foundations upon which engineering practice may be based are weakened without the generality afforded by the principle of superposition.

To understand why nonlinear control is implied in optimizing processes, it is necessary to appreciate the fact that a linear control system is, by definition, non-adaptive. Once the control parameters have been chosen in a linear system they are fixed (until manually changed). These control parameters may be visualized as weighting coefficients ascribed to the past, present, and future states of the system. The overall dynamic system behavior is determined by summing up these weighted past, present, and possible future system states regardless of the type of inputs or disturbances. In simple single loop-control systems this selection of the control parameters or weighting coefficients of past, present, and future behavior corresponds respectively to choosing the amount of integral, proportional, and derivative control action. This means that, at best, a linear control system must always be a compromise. If the past is heavily weighted, the system will tend to be sluggish. If the present and possible future states of the system are weighted more heavily than the past, the system may be capable of adjusting to sudden changes, or correcting for major disturbances, but there is the danger of erratic, unstable behavior. In practice "middle-of-the-road," or compromise, control parameter values must be chosen.

On the other hand, one form of an adaptive control system will have an ensemble of sets of control parameters from which to choose. The particular set chosen at any instant will depend upon the state of the process variables. The system will continuously switch from one set of parameters to another in order to satisfy an optimizing criterion in terms of maximum efficiency or economy as mentioned above. This type of control system will "learn from experience" and adapt to many different situations. By definition, adaptive control is of necessity nonlinear control.



Dr. Charles F. Taylor discusses nonlinear adaptive control for optimizing processes.

A useful by-product derived from this nonlinear control concept is that system performance becomes nearly independent of process conditions, such as weakening of catalyst activity in a petroleum process. An advantage of nonlinear adaptive control is that a detailed analytical description of the process is not required in order to achieve optimum performance. This benefit is of particular importance in petroleum processing where it is exceedingly difficult to obtain valid transfer functions or analytical models of the processes.

Fortunately, with the advent of reliable digital computers that can be "married" to complex processes, the future for nonlinear adaptive control is bright. Digital techniques are well suited to this method of control since the ensemble of sets of control parameters are finite and discrete. Further, sampling (in time) techniques may be employed.

Enter nonlinear adaptive sampled-data control systems!

By applying the latest proven techniques, our well-qualified staff at Daystrom Systems is prepared to take single responsibility of assembling and installing a system to meet your needs. We are currently compiling a file of new applications and papers on various parts of systems, both industrial and military. If you are interested in receiving the file and periodic additions, please write us.

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RAMBLINGS ON INSTRUMENTATION

Foot notes on the E.S.* hassle

1 . . . Granting the need for wider recognition of the E.S.* problem and possible solutions (e.g., more and better high school science training, expanded technician training, more intelligent use of engineers, etc.), isn't the "hit-the-panic-button" posture we find ourselves in (as a nation) a bit embarrassing and out-of-character? I always thought we were more interested in quality than quantity—and that with the obvious disparity between the population of the U.S. and that of Russia, we can't play a "numbers" game. There is a rather authoritarian aura to the "everyone-must-take-physics-or-else" proposals being made these days which strikes me as being somewhat at odds with the free-choice system which, with all its faults, produced our Bushes, Shockleys, Campbells and hosts of less well-known but darn competent engineers and scientists.

2 . . . If, as a means of relieving the shortage, engineers are better staffed with technicians (as we believe they should be), won't the engineer's career progress be more and more dependent on his administrative skills? He will then be judged on the effectiveness with which he *and* his "staff" produce ideas or solutions.

And if this be true, shouldn't the engineering curriculum contain more *human relations* training as well as more scientific training? *Engineer Shortage

She shivers and she shakes . . .

Here's a case where Good Dame Necessity foaled another invention (or at least an ingenious device). A plaintive call from a mining company up in the land of Sky Blue Waters informed us that our Hays draft controllers were turning in a rather spotty performance.

Our men were on the scene instanter. The problem was apparent. Near the furnace where the Hays draft controllers are used is a group of vibrating-type feeders. Their constant shivering and shaking was causing our draft controllers to stutter, resulting in the controlled dampers opening and closing in response to the vibrations rather than to the draft that was supposed to operate them.



Back to the old drawing board went the Hays trouble-shooters. A week later they were again at the scene of the tremors, armed with an adjustable time delay relay. This gimmick was designed to enable the controller sensing element to "roll with the punch," controller contacts energizing the damper power units only after the contacts were made for a predetermined time period. Momentary contacts due to vibration have no effect. The controllers have been working happily ever since, doing the fine job of draft control for which they were so lovingly designed. And another valuable bit of practical problem-solving is added to the Hays volumes on How-to-Help-Customers. We think that now we might very well be able to design controls that are fully earthquake-proof.

Low pressure plug

Did you know that Hays has the most complete line of direct-reading low pressure measuring instruments in the industry? From minimum range of 0 to 0.2" water to maximum of 0 to 120" water . . . horizontal or vertical scales. Packaged in standard cases, like 14" high by 2¼" wide per unit . . . multiple vertical scale gauges, horizontal scale units of 5" x 7", 10⅝" x 13¼", and 14" x 15" size, with 3", 6", and 10¼" scale length, respectively. Write us for the complete story.

Phil Sprague Jr.

Executive Vice President

THE HAYS CORPORATION • MICHIGAN CITY, INDIANA

WHAT'S NEW

"... full computer analysis made of automatic power control ..."

coolant flow at the coupled desired settings. The setting potentiometer system can be adjusted so that any predetermined relationship between the desired flow and the desired reactor power can be set up. The simplest arrangement would be to maintain a linear relationship between these two quantities. But this leads to a drop in fuel element and coolant temperatures as power is required. To allow for this, a trimming device is provided which enables a predetermined degree of nonlinearity to be introduced.

To check the operation of the automatic power control, the measured flux-flow ratio is presented to the reactor operator. The method involves a potentiometric recorder in a resistance bridge arrangement. Inputs are derived from slave slide wires in the reactor-power and total-coolant-flow recorders.

Change-over from manual to automatic control is accomplished by setting the desired power register until the power error is less than one percent and then operating an auto/manual switch on the control desk.

The input to the automatic flux regulator loop stems from an ion chamber. Both limited proportional and on/off controllers have been investigated. A satisfactory arrangement for the former type is a combination of a gain-stabilized chopper amplifier followed by dc amplification incorporating phase-advance stabilizing networks, with ultimate magnetic amplifier output stages feeding a two-phase servomotor. Such a motor could be used to drive each fine-control rod directly, but it is considered desirable to have identical control-rod mechanisms throughout; the servomotor is therefore used to drive the variable low-frequency supply device previously referred to.

A differential-current relay—supplied with a desired total-flow signal from the potentiometer setting unit and a measured total-flow signal from the flow telemetering and summating instrumentation—is used as an on/off regulator in the coolant-flow-control loop.

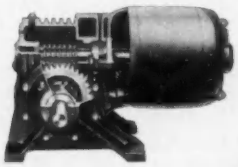
A full computer analysis has been made of the automatic-power-control system. Its performance with step changes in reactivity, ramp changes in desired power, and abrupt changes in coolant flow have been investigated.

How to dial a pair of pants



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Point is the manufacturers of this fast, efficient and extremely ingenious dry cleaning storing mechanism told Master what they needed. Light, geared-down, steady power, full start, positive stop. And whenever the attendant in a progressive shop so equipped dials your pants, a Master Gearmotor delivers the goods.

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Motor Ratings	⅛ to 400 H.P. All phases, voltages, frequencies.
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Construction	Open, enclosed, splash-proof, fan-cooled, explosion-proof, special purpose.
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Installation	Horizontal and vertical, with or without flanges and other features.
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The system functions quite satisfactorily with a neutron-flux regulator dead band of plus or minus 0.3 percent of full power, and with amplifier saturation and full servomotor speed at an error of plus or minus 2 percent full power. For a 4.5×10^{-4} K step change in reactivity (where K is reactivity) the maximum power error during the transient approaches 10 percent and regulation returns to plus or minus one percent in about 20 sec. As far as the on/off flow regulator is concerned, with an error dead band of plus or minus 0.5 percent the coolant flow error never exceeds about plus or minus 0.7 percent when making load changes.

Gas supply system. The supply of CO_2 gas to the reactor to compensate for losses during such operations as fuel charging and discharging is automatically controlled. The effect of the control system, which uses mean-gas temperature and pressure information, is to maintain a constant mass of gas in the working circuit. A number of safety valves is provided.

Western Follows TWA Lead in Automatic Reservations

Another flight reservation system has been designed by Teleregister Corp., this one for Western Air Lines. It differs from the system built for Trans World Airlines (CtE, December '56, p. 154) in two respects: it is simpler (there is only one magnetized drum for storing data on seat availability), and it is not called "Magnetronic Reservisor", as TWA's is. (This may indicate that TWA has purchased the name for itself.)

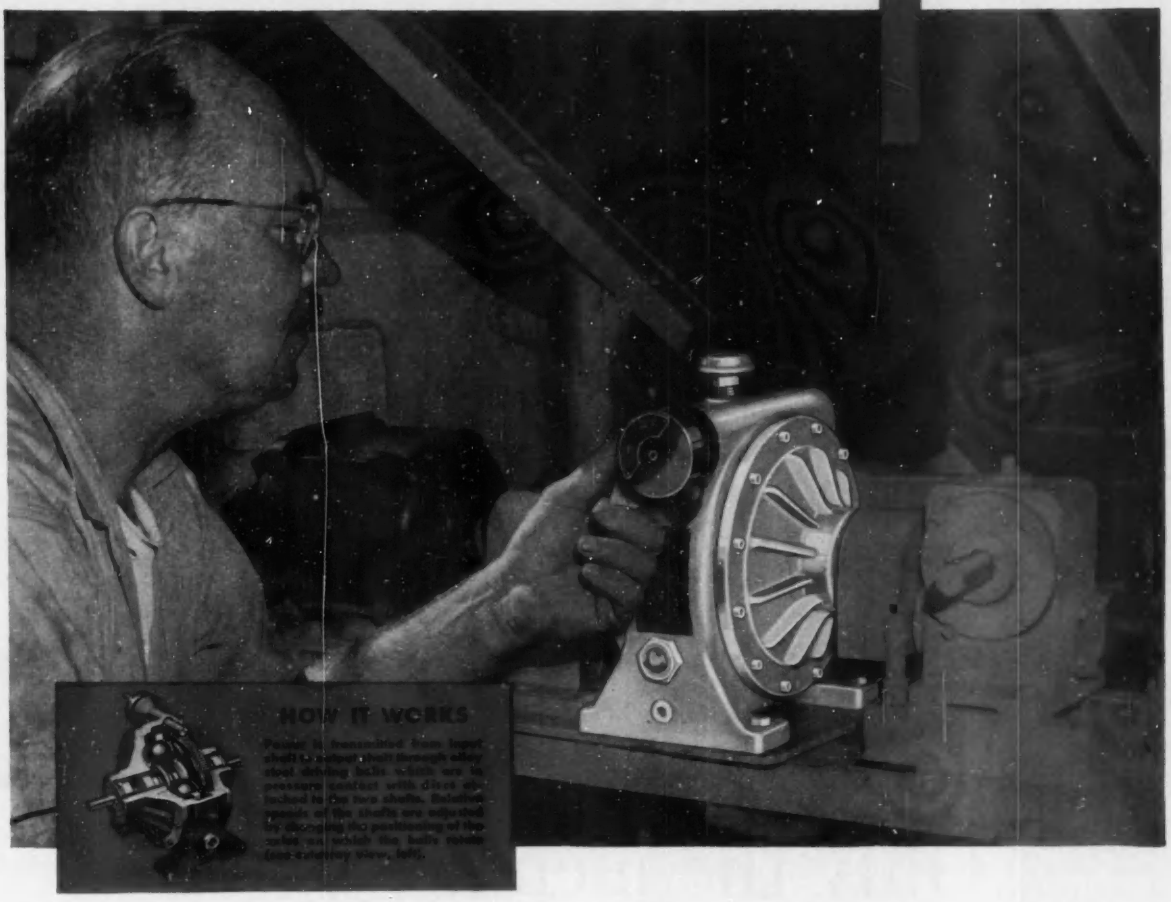
Starting next year, Western's system will handle 90 percent of all flight reservations at the 47 cities on its 6,350-mile network. Said to be planned specifically for Western's operations, the system will enable ticket agents at any one of 73 sales offices to determine instantly what seats are available on up to 2,000 flight segments 31 days in advance.

The magnetized drum, to be located at Western's Los Angeles headquarters, will store an inventory of seats available on all flights, and this data will be available to all ticket offices equipped to receive it.

The main inventory automatically corrects after each sale or cancellation. Other airlines that are adopting similar electronic reservation systems: Eastern Airlines and Pan-American.

Major chemical producer meters flow of catalytic agents with Cleveland Speed Variator

A chemical research worker adjusts the manual control knob on the Cleveland Speed Variator to set the metering speed. Various types of regulating mechanisms can be mounted on the Variator to provide automatic adjustment by remote control.



IN the research department of a major chemical plant, catalytic agents are metered and their flow varied with precision accuracy. This control is exercised with a Cleveland Speed Variator.

A ¼-horsepower electric motor is connected to the Cleveland Speed Variator driving a pump through a 25-1 speed reducer. Being infinitely variable, the Variator gives stepless speeds over its full 9:1 range—from ⅓ to 3 times input speed. Pumping speed can be varied from 207 to 23 rpm. This provides the necessary speed range for metering the various types of catalytic agents.

Available in eighteen standard types and sizes, the Cleveland Speed Variator offers these major advantages: 1. An extremely compact unit; 2. Almost any input speed up to 1800 rpm—clockwise or counterclockwise; 3. Constant horsepower output over a 9:1 range, or constant output torque with a 6:1 range; 4. Infinitely variable over entire speed range; 5. Rapid response to speed change, precise adjustment, accurate maintenance of settings; 6. Long life and minimum maintenance; 7. Ample bearing support for overhung pulleys on either input or output shafts.

Write for Bulletin K-200 for detailed description of the Cleveland Speed Variator, with photographs, sectional drawings, rating tables and specifications.

THE CLEVELAND WORM AND GEAR COMPANY

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Among the companies spearheading man's conquest of the sky are nine of the GPE Group. Their contributions are basic—technological bench marks such as—

• the only compass systems that *always* know where north is, whatever the plane does, wherever it goes: Kearfott's stable-platform gyro compasses;

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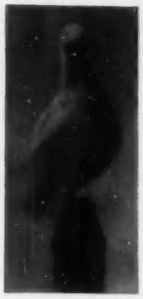
• the only airborne navigation systems in operational use guiding planes automatically and with unprecedented accuracy — anywhere, in any weather: GPL Doppler autonavigators.

Inertial navigation, missile guidance, photoscience, and certain nuclear power applications, are some other phases of aviation in which GPE companies are deeply and jointly involved. And while many of the products of the GPE companies — particularly in the field of aviation—serve defense needs today, the important scientific advances they embody are "plowshares" for tomorrow.

Aviation is but one industry in which GPE companies work. A brochure describing the activities of the group is available. More than a dozen basic industries are served by products resulting from GPE coordinated technologies and resources.

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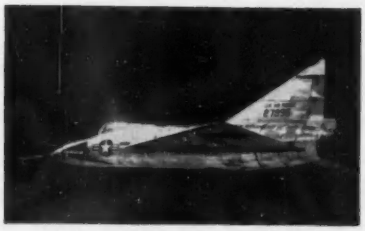
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For brochure describing the work of the GPE Group, write to: GENERAL PRECISION EQUIPMENT CORPORATION, 92 Gold Street, New York 38, New York.

Recommended Practice for Dynamic-Response Testing Readied for Review

The first of a series of ISA recommended procedures for determining the dynamic performance of process-control instruments is now out of committee and ready for review. These general recommendations, applicable to all dynamic-response testing, form the foundation for specific recommended practices for:

- devices or systems with pneumatic outputs
- devices or systems with electrical outputs
- automatic valves and other final control elements
- display and recording equipment

Both the general and the specific recommended practices will cover test equipment, test procedures, and data presentation.

Led by Fred H. Winterkamp of du Pont's Orange, Tex., plant, the subcommittee that formulated the procedures has so far confined its efforts to measurement and control equipment for the material processing industries. In line with ISA's expressed interest in extending membership to the machine-tool, heavy-production, and aeronautical fields, Winterkamp's subcommittee will develop recommended practices for dynamic-response testing of instruments and controls in these fields, too. Work there has been started by Harold Chestnut's AIEE Feedback Control Systems Subcommittee on Definitions, Symbols and Specifications.

On the ground and in the air

While Winterkamp's group is concerned with primary measuring elements, transmitters, regulators, recorders, and valve actuators of stationary plants, Chestnut's group covers airborne synchros, gyros, servomotors, magnetic amplifiers, hydraulic components, potentiometers, accelerometers, integrators, and analog-digital devices.

Devised to represent dynamic performance in a uniform way, the first recommended practice should assure its users a maximum of valuable data for control-system design per testing dollar. The contents will deal with:

Factors in dynamic response testing
- Use of data
- Interaction
- Nonlinearity
- Power supply to tested device

Recommended tests
- Input signals
- Loading

Test equipment and procedures
- Data required
- Generalized test setup
- Test equipment
- Testing procedures

Data presentation
- Sine-wave test data
- Step-test data
- Supporting information

Glossary of terms

Well aware of the practical aspects of control-system design and test, the subcommittee has paid particular attention to interaction and nonlinearity and to the regulation of the power supply to the tested device. The recommendation states specific conditions for testing which will not hide interaction and nonlinearity but which will so extract the data that they can be correctly combined with data for other devices in a proposed system. The subcommittee contends that the practice in the electrical field–specifying degree of regulation–also applies to the process instrument field. With this information the system designer can determine performance at high frequencies, when the system demands high power.

Help over the hurdles

This recommended practice still has to clear a few hurdles:

- review by a board
- final approval by the parent Recommended Practices Committee of ISA
- publication as a tentative Recommended Practice RP-26:1

The recommendation is valuable because of its general application and because it takes into realistic account the special nature of process-control instruments. The subcommittee will welcome the comments of control en-

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gineers in all industries. For a copy write to: H. S. Kindler, Secretary, Standards & Practices Board, Instrument Society of America, 313 Sixth Ave., Pittsburgh 22, Pa. Send a copy of your letter to F. H. Winterkamp, E. I. du Pont de Nemours & Co., Inc., Orange, Tex.

ISA Weighs Going "Pro"

Establishment of membership grades in ISA—separating professionals from nonprofessionals—would mean a major switch for the association from a trade group to a "full-fledged professional society". The reorganization was proposed at the Second Annual President's Mid-Winter Conference at St. Petersburg, Fla., late last February.

Four major decisions were made by the society's Executive Committee at that time. All are slanted at increasing the professional stature of the group. The next step is to submit the proposals to the society's membership for a vote. The big four:

1. Professional status—The Executive Committee accepted unanimously the Society Structure & Planning Chairman's report recommending the membership grades. Adoption could qualify ISA for "professional status" according to the standards of the Engineer's Joint Council.

2. New approach in meetings—ISA plans a new tack for meetings. At the National Meeting in Cleveland, the number of papers presented will be cut to one half that given in New York last year. And those selected will have "broad-gage, engineering content".

Regional meetings, to be beefed up to focus on the application of the technology in specific fields, will be modeled on the Nuclear Instrumentation Meeting in Atlanta (April 10-12) and the Flight Instrumentation Symposium in Los Angeles (April 29-May 2).

This change prompts a controversial question to plague ISA members: is the new meeting approach a step away from true professionalism? Some members feel that meeting programs should be arranged to attract outstanding men in the field. This way, they say, ISA members will reap the biggest harvest from attendance. And attendance will multiply. Advocates of this policy cite Flight Instrumentation Symposiums as examples. High-quality, high-level, technical papers have rapidly given these re-

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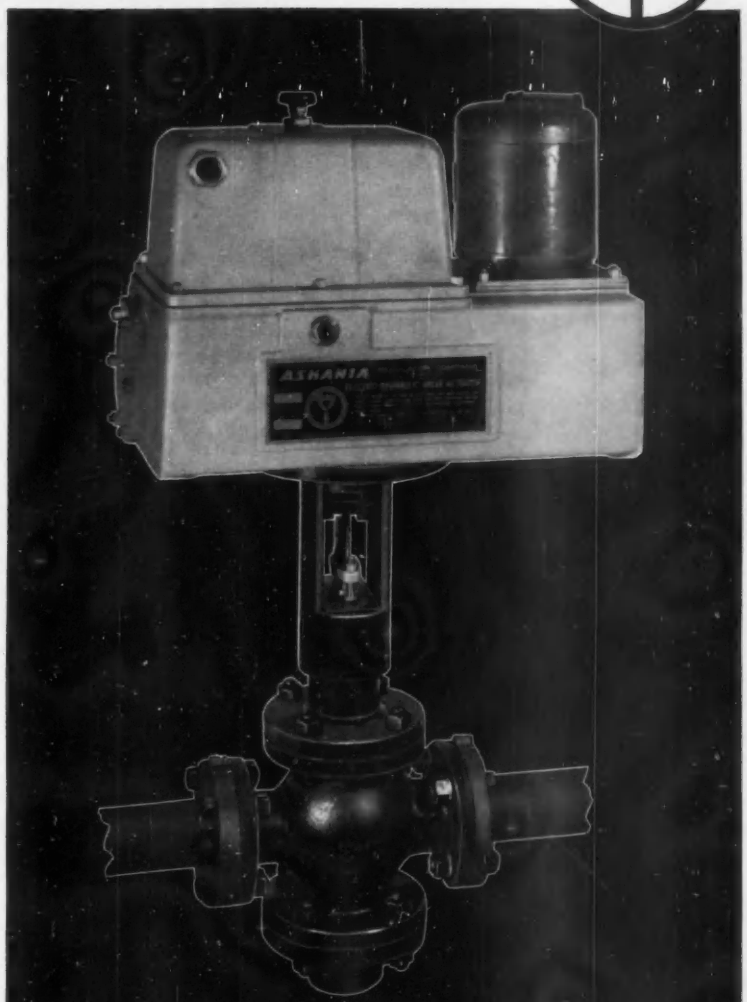
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Bulletin #38.2 explains that the ASKANIA *Electro-Hydraulic Valve Actuator can be:*

1. Adapted to any electronic controller with d-c signal output
2. Applied to any valve up to 8 inches in size and with strokes ranging from ½ inch to 2 inches
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Watts Aspirator control acts directly on input valve, giving instant compensation for fluctuating pressure demands . . . provides precise control and stabilizes pressures reaching individual pieces of equipment.

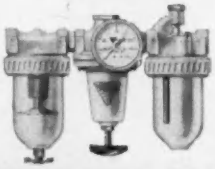
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gional meetings a good reputation.

3. Service to members—The Finance Committee has urged the appropriation of $30,000 for "membership service". Details of how the money is to be spent are yet to be worked out. But ISA's executive committee feels the fund and the recent appointment of a full-time membership relations man at headquarters will help membership grow.

4. A new name for ISA—Because its present name does not fit the broad field it serves—particularly the automatic-control area—ISA will search for a new name. A list of appropriate titles will be submitted to the April 26 meeting of the Executive Committee. Already rejected: "The Society for Control and Instrumentation".

The Florida meeting gave ISA executives a chance to take a long look at their society. The look was encouraging. Some of the reasons:

- Membership is up to 9,100 with a headquarters staff of seven.
- Number of chapters has increased to 82 in the U. S., three in Canada, and one in Aruba.
- Annual income (thanks largely to the annual equipment exhibit) has passed the $500,000-mark.

Helping guide the ISA Executive Committee in Florida were two dozen leaders from business and industry—the "President's Advisory Board"—who were invited down by president Justus Vollbrecht. This group included executives from some of the major user industries (as well as a representative from the publishing field: CtE Publisher W. W. Garey).

Defense Dept. Set to Study Data Processing

The Dept. of Defense has established a Data Systems Policy Council to study ways in which military establishments can best use modern data-processing systems. Deputy Secretary of Defense Reuben B. Robertson, announcing formation of the group, said it will start work in three main areas: 1) improvement of business systems through data-processing devices; 2) selection of equipment; and 3) personnel aspects of electronic computer installations.

The council is composed of senior policy representatives from the Army, Navy, Air Force, and Marines.

At the same time, Defense announced the formation of a Data Systems Research Staff in the office of the Assistant Secretary of Defense

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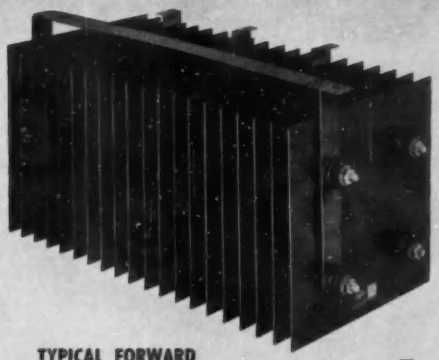
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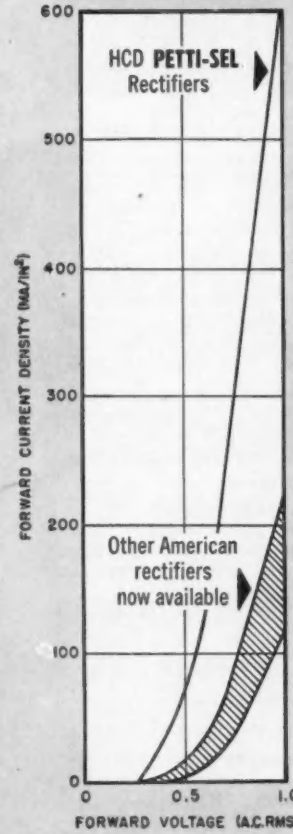
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- **Suitable for high temperature applications**

TYPICAL FORWARD CHARACTERISTICS

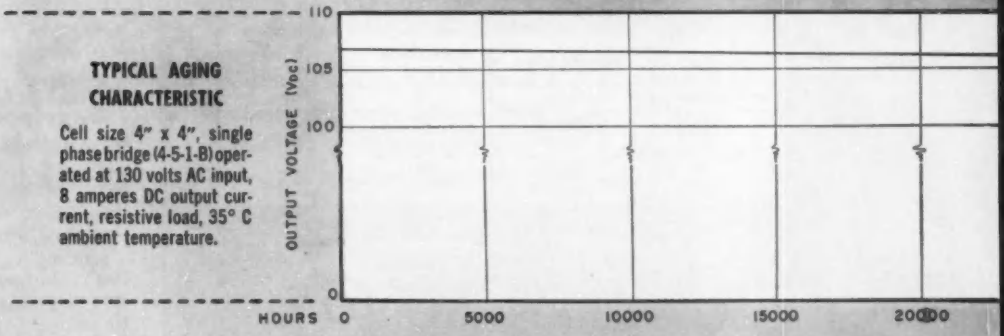


Far smaller in size than other rectifiers of the same current ratings, the new Radio Receptor HCD Petti-Sel units are manufactured under laboratory controlled conditions with fully automatic machinery, assuring new standards of product uniformity.

Field experience extending over several years with these rectifiers indicates an estimated life of 100,000 hours. This is largely attributable to the special process requiring no artificial barrier layer. Low forward voltage drop and low aging rate make the new Petti-Sel Rectifiers applicable to magnetic amplifiers and other control applications.

TYPICAL AGING CHARACTERISTIC

Cell size 4" x 4", single phase bridge (4-5-1-B) operated at 130 volts AC input, 8 amperes DC output current, resistive load, 35° C ambient temperature.



Watch for further announcements of unique developments on these history-making rectifiers. If you would like our new bulletin as soon as it is available, write today to Section C-4R.

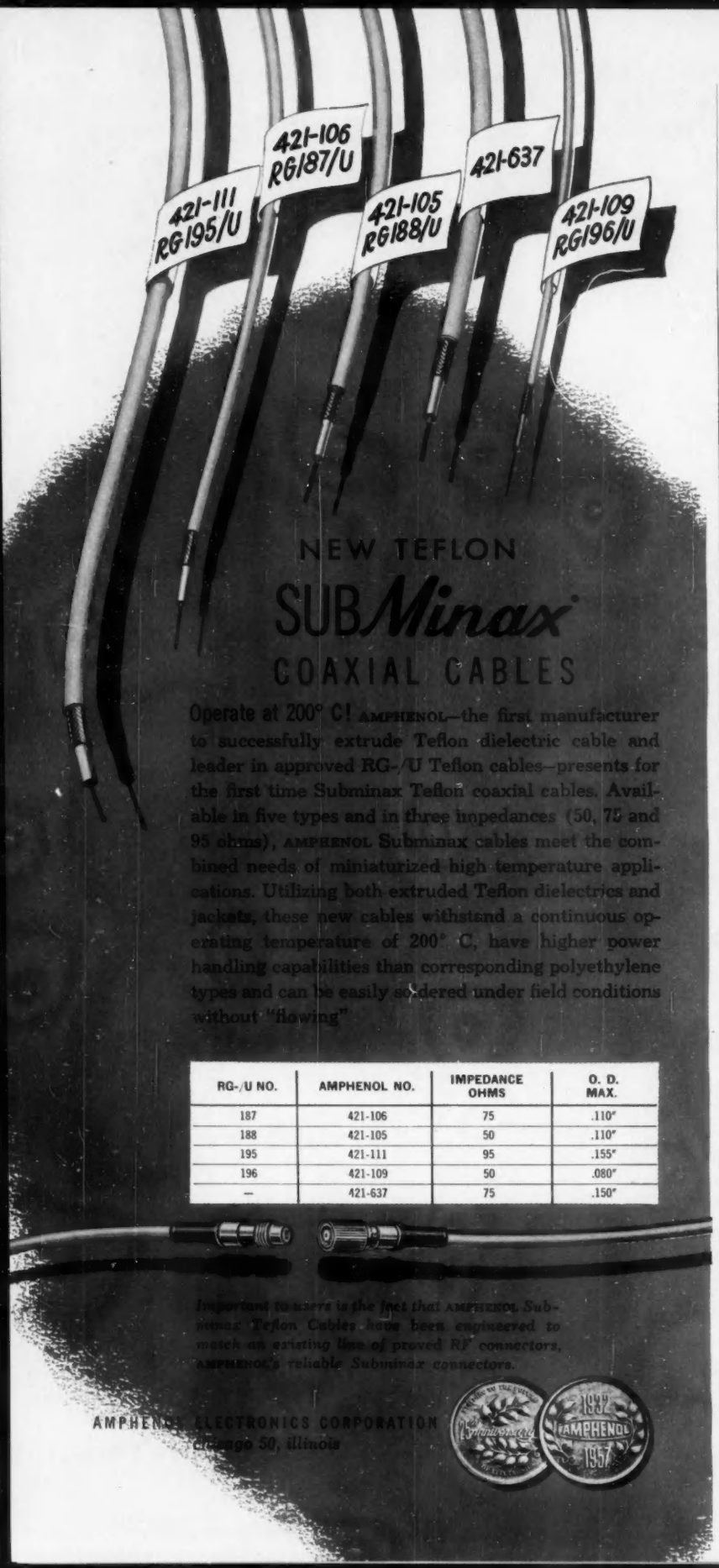
Semiconductor Division

RADIO RECEPTOR COMPANY, INC.

Radio and Electronic Products Since 1922

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Radio Receptor Products for Industry and Government: Selenium Rectifiers • Germanium Diodes Thermatron Dielectric Heating Generators & Presses • Communications, Radar & Navigation Equipment



WHAT'S NEW

(Comptroller). This group will provide research assistance to the policy council. Charles A. Phillips will serve as director.

Summer Courses Announced

Colleges are readying another summerfull of special courses in the field of automatic control. First 1957 announcements come from the state of Michigan:

- A special computer summer program at Wayne University
- Intensive courses in automatic control at the University of Michigan in Ann Arbor.

The fifth special summer program at Wayne State University's Computation Laboratory consists of three courses, each one week long. The schedule:

June 3-8. Introduction to Computers and Their Applications.

June 10-15. Data Processing in Business and Industry.

Sept. 1-14. Industrial and Management Computer Applications.

Additional information and applications are available from: A. W. Jacobson, director, Computation Laboratory, Wayne State University, Detroit 2, Mich.

At Ann Arbor, the University of Michigan's College of Engineering has announced two intensive courses for engineers who want a basic understanding of the field of automatic control but who can spare only a few days.

Course I consists of fundamentals in the fields of measurement, communications, and control, as well as some basic work in nonlinear systems. It is scheduled for June 17-22.

Course II will take up applications of these fundamentals to more advanced problems. This class will meet from June 24 to 26.

In both courses, there will be four hours of lectures each morning and three hours of laboratory demonstration each afternoon.

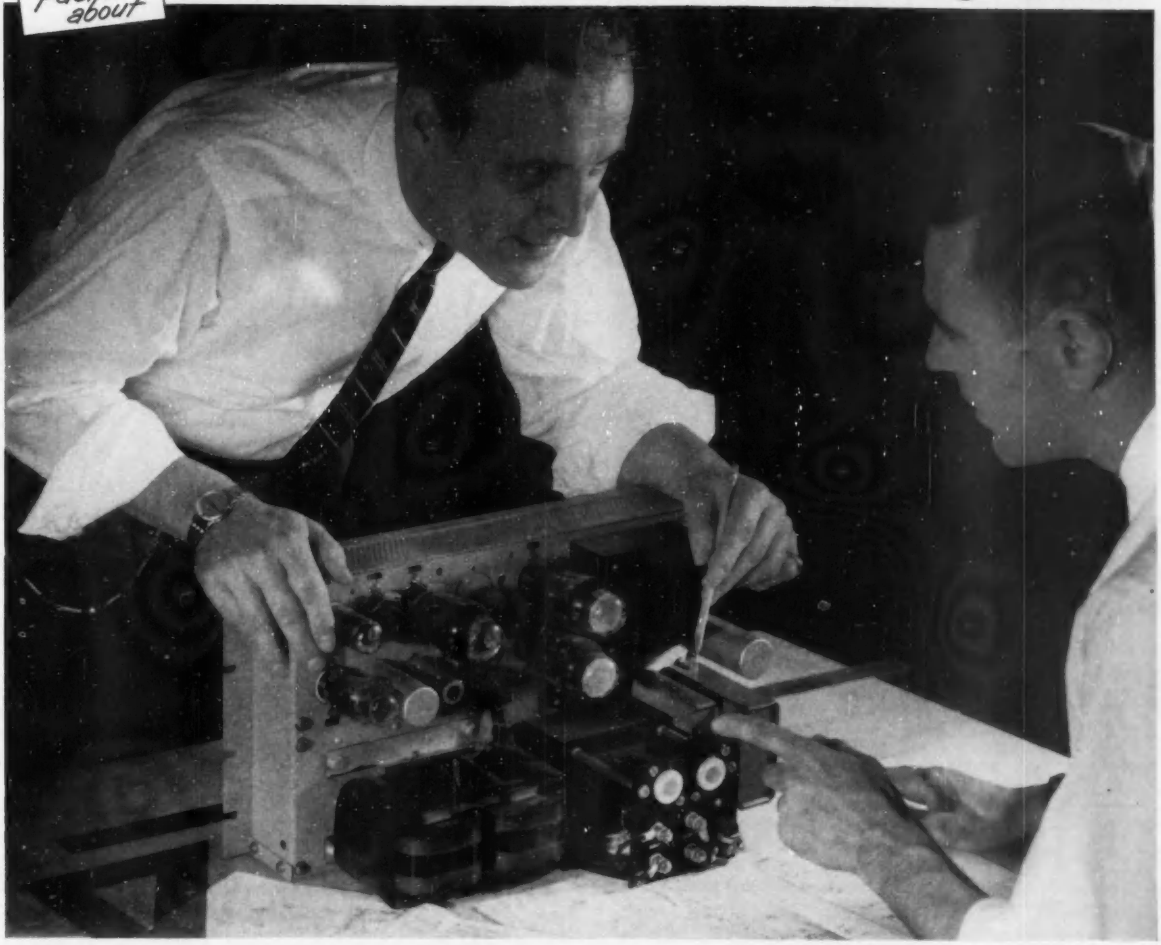
Closing registration date is April 15. For additional information write: Prof. L. L. Rauch, Room 1521, East Engineering Building, University of Michigan, Ann Arbor, Mich.

Flight-Test Symposium for West Coast

Third Flight-Test Instrumentation Symposium has been scheduled for

Facts about

STABILINE® Automatic Voltage Regulators



STABILINE type IE (Instantaneous Electronic) is available in 115 volt units — input range from 95-135v. and 230 volt units — input range from 195-255v. STABILINE type IE5101R shown above.

"Here's how to Build-in Automatic Voltage Regulation"

"No matter how good your control instrumentation is, it is not going to be precisely accurate at all times unless the input voltage is precisely *constant*.

"You just can't get better automatic voltage regulation equipment than with this STABILINE. At no load, full load or any intermediate stage it maintains constant *output* voltage regardless of line fluctuations.

"This sensitive, yet ruggedly constructed, automatic voltage regulator is a must component in today's voltage sensitive apparatus."

Three types of STABILINES are available for individual needs:

Type IE (*Instantaneous Electronic*) is completely electronic, instantaneous in action, with no moving parts. Constant output voltage is maintained regardless of line or load fluctuations.

Type EM (*Electro Mechanical*) has zero waveform distortion. Insensitive to magnitude and power factor of the load. Highly efficient.

Type TM (*Tubeless Magnetic*) has no moving parts . . . no tubes . . . no transistors. Ideal for unattended locations or where failure can never be tolerated.

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PROVIDES 24,000 8-Bit BINARY CODE GROUPS PER SECOND

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- Volume only 440 cubic inches
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Write for complete data and price sheet.

Personnel Inquiries Invited

RADIATION Inc. Melbourne, Fla. Orlando, Fla.

Electronics • Avionics • Instrumentation

WHAT'S NEW

the Los Angeles Statler Hotel beginning April 29. Sponsored jointly by the L. A. and Mojave Desert Sections of the ISA in cooperation with the Flight Test Committee of the ISA's Aeronautical Div., the technical program will trace the development of a flight-test instrument system. Morning panel sessions will develop major areas of interest and these will be followed by afternoon technical workshops. The program:

- Monday—"Optimum Aspects of an Instrumentation System"
- Tuesday—"Limitations of Current Instrumentation Systems"
- Wednesday—"Advanced Instrumentation Techniques"

On Thursday, there will be a classified tour to the Air Force Flight Test Center at Edwards, Calif. Advanced registration can be made or further details obtained by writing Eugene Spencer, ISA, 5225 Wilshire Blvd., Los Angeles 36, Calif.

IBM Launches New Scholarship Program

IBM has announced one of the largest industrial scholarship programs ever conducted. When in full operation, the IBM Thomas J. Watson Memorial Scholarship program, in honor of the late Thomas J. Watson, former IBM board chairman, will provide 50 four-year scholarships a year; the program will cost up to $250,000 per year.

Twenty-five scholarships will go to high-school seniors who are children of IBM employees, and 25 more to other high-school seniors in public, private and parochial schools. In all, 200 students a year will be supported when the program gets under way.

In addition, a minimum of 25 matching scholarships will be awarded annually by the National Merit Scholarship Corp., which will cooperate in administering the program.

Recipients will be selected on the basis of merit, without regard to financial need. The amount of the award —varying from a minimum of $100 per year to the full cost of education —will be determined by NMSC.

•

ASEE is conducting a major study into engineer recruiting and ways to develop and use engineering facilities. The project will: 1) measure quantitatively the need for engineering teachers; 2) identify and study the problems

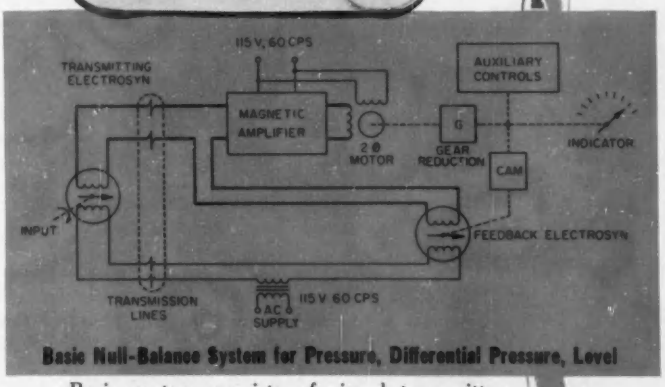
ElectroSyn Pressure Transmitter Model 501



HIGHer reliability
LOWer maintenance

- *pressure*
- *differential pressure*
- *flow*
- *level*
- *temperature*

ELECTROSYN SYSTEM



Basic Null-Balance System for Pressure, Differential Pressure, Level

Basic system consists of signal transmitter, magnetic servo amplifier, null-balance indicator. (No electron tubes or slide wires.)

• In measuring pressure the Model 501 transmitter utilizes a twisted bourdon tube as the pressure sensing element. This tube converts the pressure into shaft rotation of the ElectroSyn, a rotary differential transformer. Output from the ElectroSyn is an a-c voltage exactly proportional to the measured pressure.

ElectroSyn is a highly flexible, extremely rugged electro-magnetic system for a wide range of applications in the chemical processing, atomic power, natural gas and petroleum transmission fields. It is designed to measure, indicate, record (including analog to digital conversions), or control pressure, differential pressure, flow, liquid level, temperature.

Leading pipeline companies are using ElectroSyn systems for remote indication and data handling of pressures and flows because of system's reliability, flexibility and the fact that it can withstand a static overload of 300% of rated pressure for a 1% zero shift. For complete information write for Technical Bulletin B257.

NORWOOD CONTROLS
UNIT OF DETROIT CONTROLS CORPORATION
938 Washington Street, Norwood, Mass.

NORWOOD CONTROLS

See ElectroSyn System in operation at PIEA-PESA Show, Booths 64 - 67, Shamrock Hotel, Houston - April 16 - 18

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. . . quickly pinpoint design and engineering problems

" . . . If you think high speed movie photography is of interest only to businessmen of the Buck Rogers type, think again. It has fascinated some down-to-earth folk at (both) ends of the American economy: Television ad men . . . factory managers . . . engineers.

"Factory managers are using the time machines to find for the first time what is really going on in their plants.

" . . . For example Paper Mate Manufacturing Co., Burroughs Corp., Ethyl Corp., General Mills, General Motors, Ford are just a few corporations using high speed photography to stop time . . . freeze motion."

FASTAX cameras are the most widely used high speed motion picture and oscillographic cameras because they are the most versatile . . . have the widest speed ranges . . . offer the most complete line.

WRITE and see how high speed photography can help save engineering time . . . cuts down on development time because it enables your engineers to pinpoint problems more readily . . . helps picture the answer. Wollensak Optical Company, Rochester 21, New York.



WOLLENSAK
OPTICAL COMPANY
ROCHESTER 21, NEW YORK

WHAT'S NEW

to be solved in meeting this need—the financial problem, the conditions required to make college teaching competitive with other engineering careers, the unique satisfaction and rewards of the teaching profession; 3) initiate and encourage activities to increase the supply and quality of teachers.

•

British fighter bombers will be equipped with a U.S. low-altitude bombing system for low-flying jets. The State Dept. has authorized Minneapolis-Honeywell Regulator Co. to sell LABS systems to the RAF.

•

Automatic Classification Yard System, called VELAC, has been installed at Mon Southern yards outside Pittsburgh by Union Switch & Signal Div. of Westinghouse Air Brake Co. The new equipment provides for completely automatic operation for all cars moving through a master retarder and into a group of classification tracks.

•

Isotope Boron 10 is now available in kilogram quantities. The AEC announced that the material is being produced in a plant operated by Hooker Electrochemical Co. Main use is as an alloying agent in steel to produce neutron absorbing shielding. Other uses: instruments for measuring radioactivity. Cost: about three times the cost of gold.

•

The first automatic railroad signal control system in Australia has been proposed by State of Queensland for the Townsville-Mt. Isa Railroad. Estimated costs of the system range between $7 and $9 million.

•

The London firm of J. L. Shaw, Ltd., claims to have developed the first vhf continuous indicating moisture meter. The company says prototypes already have been installed.

•

The first electronic data-processing center in South America was opened by IBM of Venezuela. Heart of the Caracas installation is an IBM 650 magnetic drum data-processing machine. The center will be available to tackle problems ranging from payroll accounting to oil exploration.

•

Electronic tubes destined for missile guidance systems are being x-rayed by Raytheon Mfg. Co. in an effort to improve reliability of the tubes. An automatic x-ray detector photographs up to 18,000 subminiature tubes a day, looking for defects in the 15-20 welds found in every tube.

Rugged E-I Compression Seals are the industry's standard for superior performance in commercial and military service. Practically indestructible, they provide the maximum immunity to shock, vibration and temperature changes.

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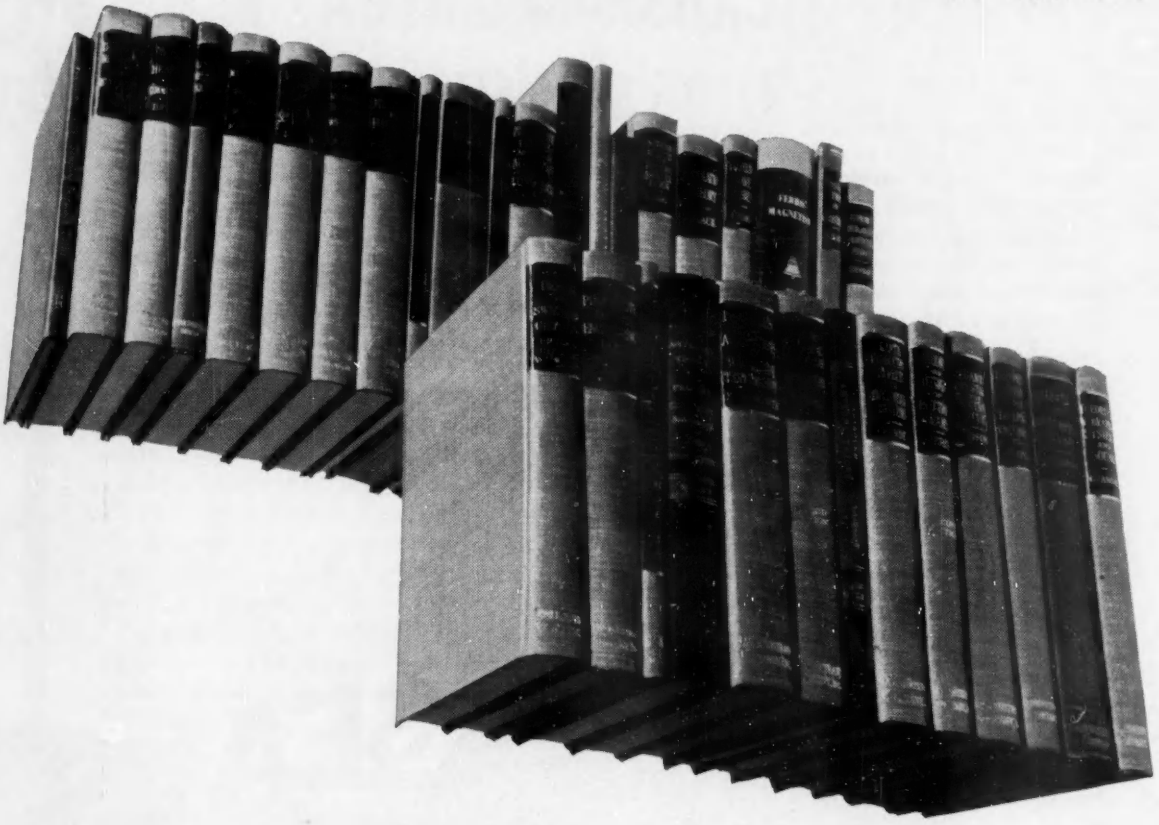
Single Lead Terminals—Available in standard or custom designs.

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Transistor Closures — Standard sealed bases, cans and diode closures available.

Multiple Headers—for every hermetic sealing requirement.

The books...



How the scientific world shares in fruits of the telephone art

In their work to improve telephony the scientists and engineers of Bell Telephone Laboratories make important findings in many sciences. They thoroughly report these findings in professional journals and magazines. But sometimes, as knowledge accumulates in a vital field, a "treatment in depth" is prepared in book form.

Bell Laboratories authors have written 36 books to date and others are in preparation. Many have become classics in the Laboratories' primary field of communications. Many have become standard works of wide application because they provide a fundamental guide for technologies in other fields. For example, the design of automatic switching systems is of primary importance in computers; statistical quality control provides the indispensable basis for economical manufacture. Through their books these scientists and engineers and the Laboratories attempt to repay benefits they receive from the published works of others.

The pictures on the opposite page show some Bell Laboratories authors of technical books. A complete listing of titles may be obtained by sending in this coupon.

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Harold S. Black, B.S. in E.E., Worcester Polytechnic Inst., author of "Modulation Theory."



John R. Pierce, Ph.D., California Inst. of Tech., author of "Traveling-Wave Tubes."



Richard M. Bozorth, Ph.D., California Inst. of Tech., author of "Ferromagnetism."



W. Thornton Read, M.S., Brown University, author of "Dislocations in Crystals."



Hendrik W. Bode, Ph.D., Columbia University, author of "Network Analysis and Feedback Amplifier Design."



Walter A. Shewhart, Ph.D., University of California, author of "Economic Control of Quality of Manufactured Product."

WHAT'S NEW

AROUND THE BUSINESS LOOP

American Skill Seasons Three Foreign Developments

The European computation center established recently in Brussels, Belgium, by Electronic Associates, Inc., is one of three major foreign developments to be touched with the skillful fingers of American industry. Each represents a vital segment of the control field, and the three together make up what can be considered a classic picture. Electronic Associates' contribution is *computer analysis*; its new computation center is the latest in a program "to meet the challenge of rapidly expanding markets".

The speed with which Electronic Associates is setting up these centers is indicated by the fact that news of its Los Angeles project led off this column just two months ago (CtE, January, p. 44). The one in Brussels, to be ready by next summer, will be staffed as much as possible with European scientists, President Lloyd F. Christianson said. He added that "We feel that there is a growing need in industry for a facility such as we will establish in Brussels. It will prove particularly beneficial to the smaller companies which have not yet found it feasible to invest in their own computation facilities. One of the purposes of this center is to educate business and industry on the capability of analog computers to economically solve many of their problems with an enormous saving of time and money."

It is interesting that one of the primary reasons for the selection of Brussels for the new center was the "extremely cooperative attitude" of this country's Ministry of Economics, which passed along its government's OK to Electronic Associates in record time. EA also considered these factors, however: Brussels' central location, its good transportation facilities, its key role in NATO research, its good relations with other European countries, and its highly stable and freely convertible currency.

The second element in the classic picture is *marketing and management*, and this is supplied by Arthur D. Little, Inc., industrial research company of Cambridge, Mass., which recently sponsored a British complement near Edinburgh, Scotland. A university atmosphere, for which the Institute of Seaweed Research, the previous tenant of the laboratories, set the precedent, will prevail: scientists from Great Britain and the continent will be free to publish their findings and discuss their work.

Coordinating the new Arthur D. Little Research Institute and its American counterpart will be Dr. Lawrence W. Bass, formerly director of research for the Borden Co., assistant director of the Mellon Institute, chemical research director of Air Reduction Co., and vice-president of U. S. Industrial Chemicals Co. He will have his headquarters in Cambridge. Dr. F. N. Woodward, formerly director of the Institute of Seaweed Research, will direct operations at the site.

Bass, who also is a vice-president of ADL, is one of three ADL men who become American board members of the new institute. The others are Raymond Stevens, president of ADL, and William A. W. Krebs Jr., vice-president. Among the British board members are the Rt. Hon. Lord Bilsland, president of the Scottish Council, chairman of the board; David S. Anderson, director of the Royal Technical College, Glasgow; Robert Erskine-Hill, and Ian Heilbron, director of the Brewing Industry Research Foundation. Projects are already being started by the new institute for American industrial sponsors.

The third development is a $30,000 systems simulating laboratory purchased by the Spanish government. Builder is Servo Corp. of America, which thus contributes the element of *precision hardware* to the picture. The Servolab sold to Spain's Ministry of Defense is a modular-type design and testing laboratory that breadboards, analyzes, and simulates any type of servo control system by a rapid interconnection of building blocks. Spain is evidently the first foreign nation to buy the system. Servo Corp. recently described it in an entertaining and off-beat publicity booklet (CtE, Dec. '56, p. 164).

Big Doin's in Society: Beckman, Statham Labs Wed

One of the most significant company mergers in the field in recent months has brought together Beckman Instruments, Inc., and Statham

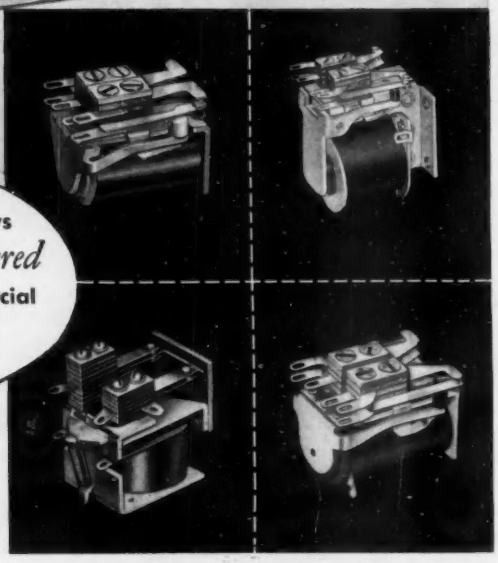


for efficiency...
for dependability...

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Comar Relays, "tailor-made" to fit the job, are easier to install, more efficient, more dependable. You get the EXACT electrical characteristics and physical size you want...you get custom quality ...yet you pay no more.



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WHAT'S NEW

Laboratories, Inc. Statham, a leading manufacturer of precision pressure transducers, accelerometers, and other control devices, thus joins the gigantic Beckman plant, whose Scientific, Berkeley, Helipot, Spinco, and International Divs. sprawl all over California and overflow into Connecticut, New Jersey, West Virginia, Canada, and Germany. Respective year-end sales figures for the two companies, which may help to point up the importance of the merger, are Beckman, $40 million, and Statham, $5 million. A stock exchange of up to 400,000 Beckman shares for all of the Statham interests sealed the agreement.

Daystrom's Nuclear Div. Opens a Reactor Center

The Daystrom Nuclear Div. of Daystrom, Inc., has established a nuclear reactor center in West Caldwell, N. J., where it has prepared a 36,000-sq-ft laboratory to house an "Argonaut" reactor. Also contemplated is a program of "reactor training", for which 10-kw Argonaut research reactors, to be built at reasonable costs, will constitute the core. The purpose of the new center, said Division General Manager Stephen Malaker, is to implement the peacetime atomic training program to be sponsored by the AEC. The "Dart" plan, as it is called, will provide a "nuclear training package" for college and university personnel, which will include work at West Caldwell, formal engineering surveys of campus reactor sites, installations there of Argonaut reactors, and consultation.

As things were shaping up at West Caldwell, the parent Daystrom, Inc., began moving its executive offices from Elizabeth, N. J., to Murray Hill, N. J., where it will be neighbors with several other major firms in a specially zoned suburban research and office area.

New GE Lab Expands Semiconductor Research

Under Manager Harris M. Sullivan, a new General Electric Semiconductor Laboratory gets under way "to bridge the gap between basic research and semiconductor product engineering". An expansion of the work in semiconductor research done by GE's Electronics Laboratory will be the prime object of the new unit, which will be located in Electronics Park, Syracuse, N. Y. Specifically, its nucleus of 15

THE *FORWARD* LOOK INCLUDES

CYPAK

. . . to provide automatic conveyor control at the new Plymouth assembly plant

Seven CYPAK* static control systems control the scheduling of auto bodies into storage conveyors at Chrysler Corporation's new assembly plant at Newark, Delaware.

In one CYPAK system, for example, the operator can select any of 15 storage lines by just pressing a button. A similar CYPAK system unloads the bodies, in pre-selected order, again through the use of just a pushbutton.

CYPAK was chosen because of its elimination of maintenance, economical operation, and reduced space requirements.

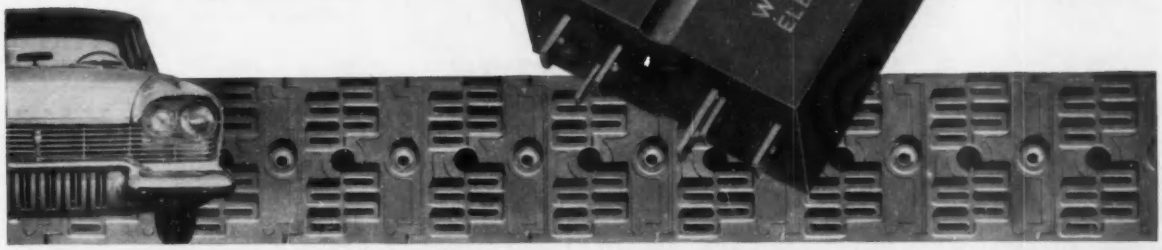
For complete information on CYPAK call your Westinghouse representative, or write Westinghouse Electric Corp., Dept. B, P. O. Box 868, Pittsburgh 30, Pa. *Trade Mark

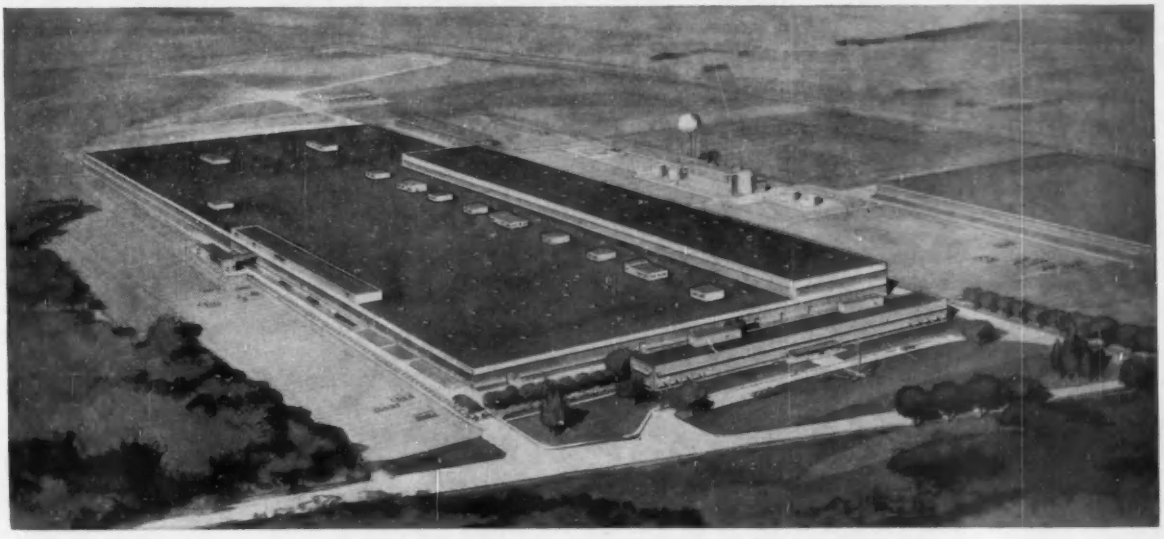
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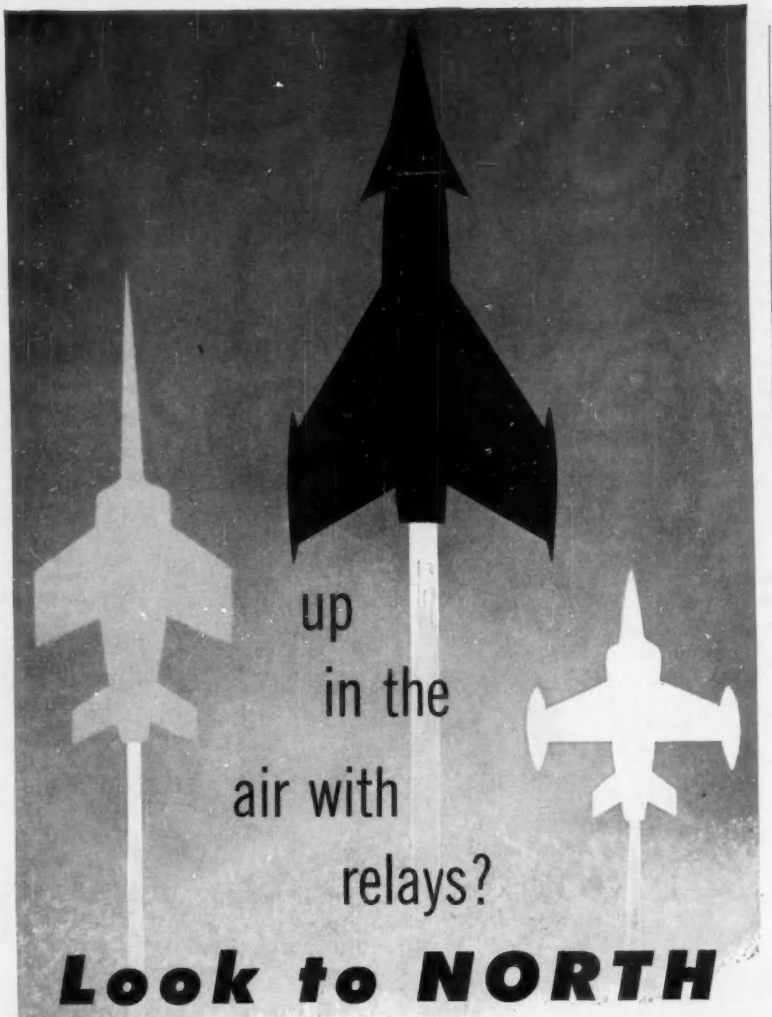


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Designed to meet MIL-R-5757C, the NORTH IR-226 is being widely used in many airborne applications that require a vibration-proof, shock-resistant, hermetically sealed, sensitive relay.



IR-226
Actual Size

NORTH IR-226 is being specified as a component in plate circuits for power amplification.

Where low-level switching requirements are highly critical the IR-226 contacts have been tested at 8 micro-amps and 30 milli-volts.

The IR-226 has demonstrated complete reliability at 40 milli-watt sensitivity.

Whether your requirements include relays for production runs or for relay engineering and design for prototype development, NORTH's 72 years of experience in engineering, design, and precision manufacture of relays for commercial and military applications can be applied to meet your demands.

INDUSTRIAL DIVISION

NORTH ELECTRIC COMPANY

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WHAT'S NEW

research scientists will work on new methods for producing more perfect crystals of germanium, silicon, and intermetallic compounds, and for placing selected impurities into pure materials to obtain alloys with desired semiconductor characteristics. It will also attempt to enlarge the number of semiconductor devices now available and the methods for applying them. Sullivan, most recently manager of the Electronics Laboratory, joined GE in 1955 after more than a decade of research in physics and chemistry.

Shell Lines Up Projects for New Applied Math Dept.

A new Applied Mathematics Dept. has been organized by Shell Development Co. in its Emeryville (Calif.) Research Center "to cope with the company's increased interest in the field of applied mathematics". It will develop mathematical and high-speed computing methods, then apply them to the costly experimental work necessary for new processes and to the Operations Research of Shell Oil Co. and Shell Chemical Co., which are investigating improved ways of carrying out existing refinery and chemical plant operations.

Head of the new department is J. Ben Rosen, a former Manhattan Project man who has also been with Brookhaven National Laboratories and Princeton University (in its Mathematical Dept. and its Forrestal Center). He joined Shell in 1954. There are three sections in the new department—analysis, operations research and statistics, and computation.

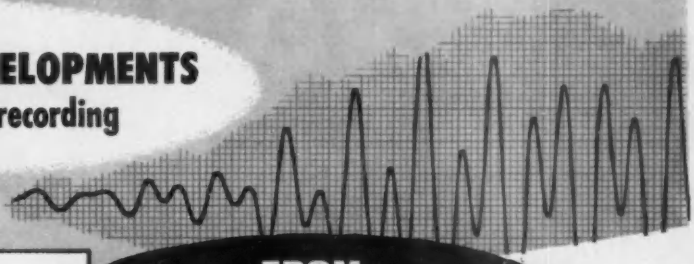
Consolidated Avionics Gets Data Reduction Contract

A digital data reduction system for testing advanced rocket engines will be built by Consolidated Avionics Corp. under a $225,000 contract with Reaction Motors, Inc. The system will gage and record pressure, temperatures, and forces inside experimental rocket chambers during tests, and automatically print out results. CAC's president, Harry R. Glixon, is a CtE author (March, p. 87).

Relay Manufacturers Elect Roughan, Pfeffer, Bohaker

New officers of the National Association of Relay Manufacturers, elected at the annual membership meeting in New York, are James V.

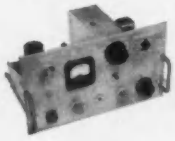
TECHNIQUES and DEVELOPMENTS in oscillographic recording



FROM SANBORN

PHASE SENSITIVE DEMODULATOR PREAMPLIFIER PROVIDES A DC VOLTAGE PROPORTIONAL TO AN INPHASE COMPONENT OF AN AC VOLTAGE WITH RESPECT TO A REFERENCE.

THE measurement of the amplitude of an AC voltage component is often necessary in performance studies of servo systems or of suppressed carrier signals over the carrier frequency range from 60 to 10,000 cps. In such cases the demodulator responds to inphase signals and rejects quadrature signals.

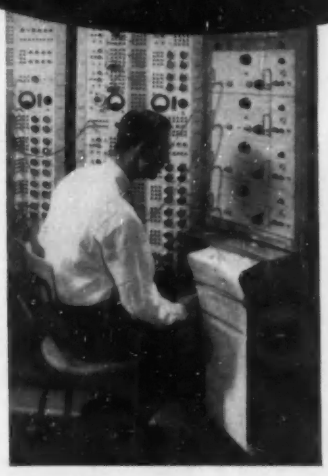


A circuit with these characteristics for use in an oscillographic recording system can be seen in the Model 150-1200 Servo Monitor (Demodulator) Preamplifier. It was developed by Sanborn as one of twelve interchangeable, plug-in front ends for "150" Series equipment, to be used with the appropriate Driver Amplifier-Power unit in any channel of a "150" system. Elements comprising the circuit from input to output, include: compensated stepped attenuator and cathode follower input circuit, phase inverter, push-pull mixer and demodulator stages, differential DC output amplifier and low pass filter. In addition, the chassis contains a VTVM to facilitate accurate adjustment of the reference voltage, and an overload indicator which lights a warning lamp when excessive quadrature voltages exist.

Adaptability to a fairly wide variety of applications is accomplished through broad input voltage, reference voltage and frequency ranges. In order, these are 50 mv to 50 v (for full scale 5 cm deflection), 10 v to 125 v; 60 cps to 10kc. Rise time with low frequency plug-in demodulation filter is 0.1 seconds; with high frequency filter, 0.01 seconds. Quadrature rejection is better than 100.1; for carrier frequencies up to 5000 cycles.

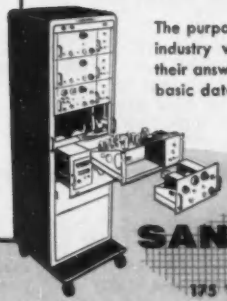
Two representative uses of the Servo Monitor Preamplifier are in the design and adjustment of servo systems, and with instruments used in the design, development or adjustment of other apparatus. The first is illustrated by use of the Preamplifier and associated equipment in the recording of the output shaft amplitude and driving frequency of an AC positional servo; the second by recordings made with a similar setup of the difference between output signals from a gyroscopically-controlled stabilizing device and the "pitch" and "roll" signals generated by a "Scorsby Table" used for testing the device under dynamic conditions.

For a detailed discussion of the principles and design considerations involved in the Servo Monitor Preamplifier, refer to the February, 1955 issue of the Sanborn RIGHT ANGLE, for Dr. Arthur Miller's article on "Measurements with the Servo Monitor Preamplifier."



BASIC FACTORS IN SELECTING OSCILLOGRAPHIC RECORDING EQUIPMENT

WHEN considering any oscillographic system or equipment for your application, three useful "yardsticks" to apply are (1) the recording method, (2) equipment adaptability, and (3) variety of equipment available. Here are the answers to the three, as they apply to Sanborn systems. In the record, rectangular coordinates accurately correlate multiple traces, simplify interpretation and eliminate errors. Permanent traces, produced by a hot ribbon stylus without ink, provide sharp peaks and notches, and clearly reveal all signal changes. One percent linearity results from current feedback driver amplifiers and high torque galvanometers of new design; maximum error is ¼ mm in middle 4 cm of chart, ½ mm across entire chart. From the standpoints of "adaptability" and "variety", Sanborn "150" equipment offers the versatility of 13 different plug-in front ends for any basic system . . . the choice of one- to eight-channel systems . . . the variety of nine chart speeds, timing and coding controls, console or individual unit packaging . . . availability of equipment as either complete systems or individual amplifier or recorder units.

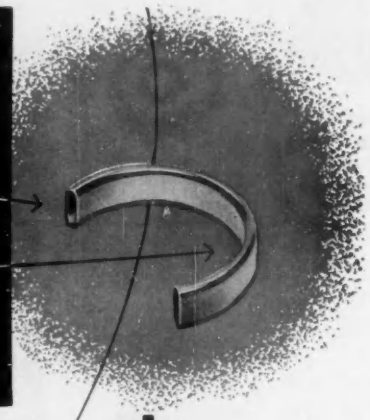


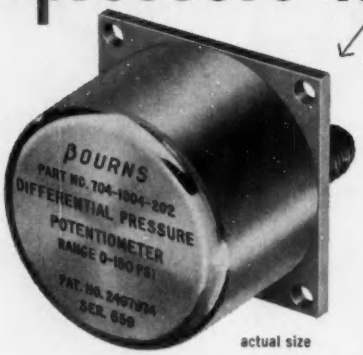
The purpose of the foregoing information is to better acquaint industry with typical oscillographic recording problems and their answers, design considerations in Sanborn equipment, and basic data on what Sanborn makes and how it is being used.

Technical literature and engineering assistance on specific problems are always available from our engineering department.

SANBORN COMPANY
INDUSTRIAL DIVISION
175 WYMAN STREET, WALTHAM 54, MASS.

BOURNS new Bourdon tube pressure transducers





actual size

—a complete line designed for high range—with stainless steel or beryllium copper construction.

Bourns—designer and manufacturer of its own Bourdon tubes—now brings this proved component to absolute and differential pressure potentiometers. Three instrument models are provided for an extensive range of applications.



Model 704
Differential Pressure Potentiometer—*for corrosive fluids*
This unit has a stainless steel Bourdon tube and fittings, to withstand fuming nitric acid and other corrosive fluids. All mechanical joints are Heli-arc welded. The instrument will measure differential pressure between two high pressure sources.

Model 705
Absolute Pressure Potentiometer
This absolute pressure potentiometer measures pressures in ranges of 0-100 to 0-1000 psia—extending the range of Bourns Aneroid Capsule instruments.

Model 706
Differential Pressure Potentiometer—*for non-corrosive fluids*
The Bourdon tube in this high range instrument is made of berryllium copper for use with non-corrosive fluids. With the low pressure port vented to the atmosphere, this unit can be used as a gage pressure instrument.

All models have a durable stainless steel case... compact configuration... excellent linearity, resolution and hysteresis. The rugged linkage system and Bourdon tube assembly provide excellent shock, vibration and acceleration characteristics. All models are now in quantity production. Write for new literature.

COPR. BL

BOURNS LABORATORIES

General Offices: 6135 Magnolia Avenue Riverside, California
Plants: Riverside, California—Ames, Iowa

WHAT'S NEW

Roughan, general manager of Consolidated Electronics Industries Corp., president; John L. Pfeffer of Struthers-Dunn, Inc., of Pitman, N. J., vice-president; and Karl H. Bohaker of Sigma Instruments, Inc., secretary-treasurer.

Other Developments

▶ Several companies which figure prominently in the control field have established new divisions and departments in recent weeks. They are:

Burroughs Corp., whose Burroughs Div. has formed a Detroit Mfg. & Engineering Div. under Lyle R. Blossom, general manager. The move is part of a Burroughs program of decentralization. Blossom, who joined the company in 1929, has been manager of the Burroughs main Detroit plant since 1953.

Westinghouse Electric, which has merged its X-Ray Div. and Industrial Electronics Dept. into an X-Ray & Industrial Electronics Div. under W. J. Delaney Jr., formerly manager of the Welding Dept. in the Motor & Control Div. H. D. Moreland and R. C. Creek continue as managers, respectively, of the X-ray and industrial electronics operations.

Sperry Gyroscope Co., whose two new divisions, Air Armament and Surface Armament, are to be managed, respectively, by Samuel Agabian, formerly works manager, and Myron D. Lockwood, formerly engineering director of surface systems. These groups, which virtually complete the reorganization of the company on the lines of more efficiency and speed of production, will continue activities at Lake Success, N. Y., where classified guided missile projects and other developments are being handled. Agabian and Lockwood will have separate teams under them, headed, respectively, by chief engineers Herbert Harris Jr. and Eric J. Isbister.

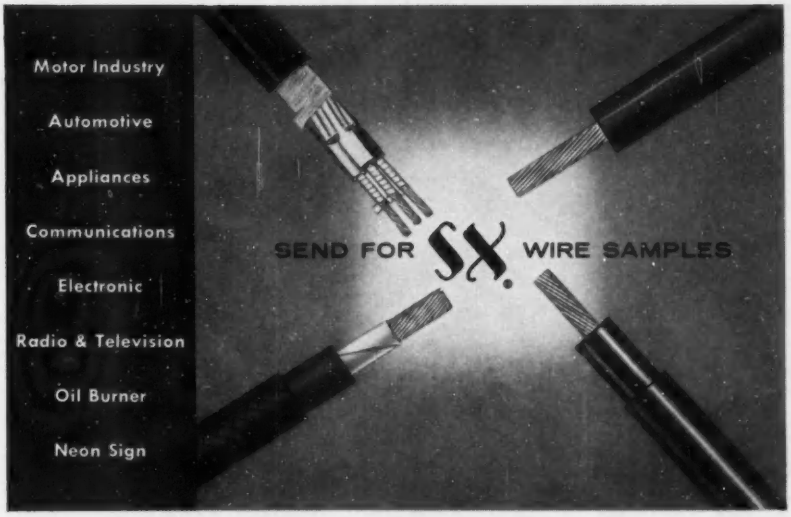
Gulton Industries, which has set up a division for research, development, and production in the fields of high-frequency telemetering systems and related communications devices, under Burt J. Bittner, an authority on telemetry antennas, who comes to Gulton from **Sandia Corp.**

Allen B. Du Mont Laboratories, Inc., whose Data & Display Dept. will be steered by Robert W. Deichert, manager. Behind the establishment of the new department is increased activity in research and development work on data pickup, processing, and

(Continued on page 182)

ESSEX ENGINEERED

WIRE and CABLE



... laboratory-developed to meet the unique requirements of your specific application!

The Essex "Extra Test®" approach to the development of quality wire products has gained the confidence of engineers in every industry where electrical wire products are a factor! The full line of lead, appliance, automotive and refrigeration wires ... plus submersible pump cable and 200° C. Sil-X® insulations are outstanding examples of the versatility of "Essex Engineering." Thorough engineering, from conductor to covering, has made available a wire of type and size with vital properties that assure you outstanding performance.

Unusual wire or cable specifications need not trouble today's engineer. By investigating the complete line of SX Wires and Cables, most wiring requirements can be quickly met by one or more of the Essex "Standards"; thus hastening delivery, affecting far greater economies, and guaranteeing an Essex Engineered "Industry Proven" product.

SX WIRE PRODUCTS®

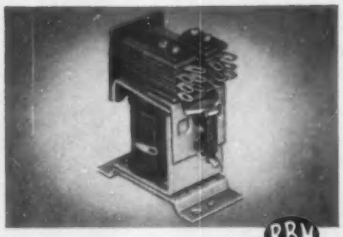
WIRE and CABLE DIVISION

ESSEX WIRE CORPORATION

FORT WAYNE 6, INDIANA

*EE

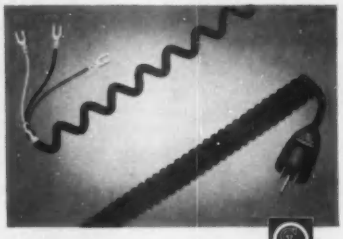
other outstanding
***ESSEX ENGINEERED**
production proven products



GENERAL PURPOSE RELAYS RBM®

A.C. or D.C. General Purpose Multipole relays. For circuit switching of electrical interlocking remote control devices. Features special cross-bar contacts for low-voltage, low current circuits or button type contacts for power switching circuits. Request Bulletin No. 1060.

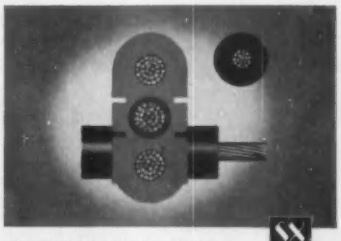
R-B-M "Control" Division
Logansport, Indiana



COILED CORDS ®

Coiled Cords automatically synchronize with moving components that are electrically powered. There are no looping, tangling cords in the way ... because Coiled Cords extend and retract as needed. Complete line of cord sets and power supply cords. Write for new literature.

Cords Limited Division
DeKalb, Illinois



REFRIGERATION WIRES SX®

The complete line of "Essex Engineered" internal, lighting circuit, heater and lead wire ... plus flexible conduit, power supply cords and thermostat cables, are approved by UL and CSA.

Wire and Cable Division
Fort Wayne, Indiana

SX WIRE PRODUCTS® ESSEX WIRE CORPORATION

GENERAL CONTROLS

REDUCES Operating Time **REDUCES** Bench Size **REDUCES** Manpower Cost

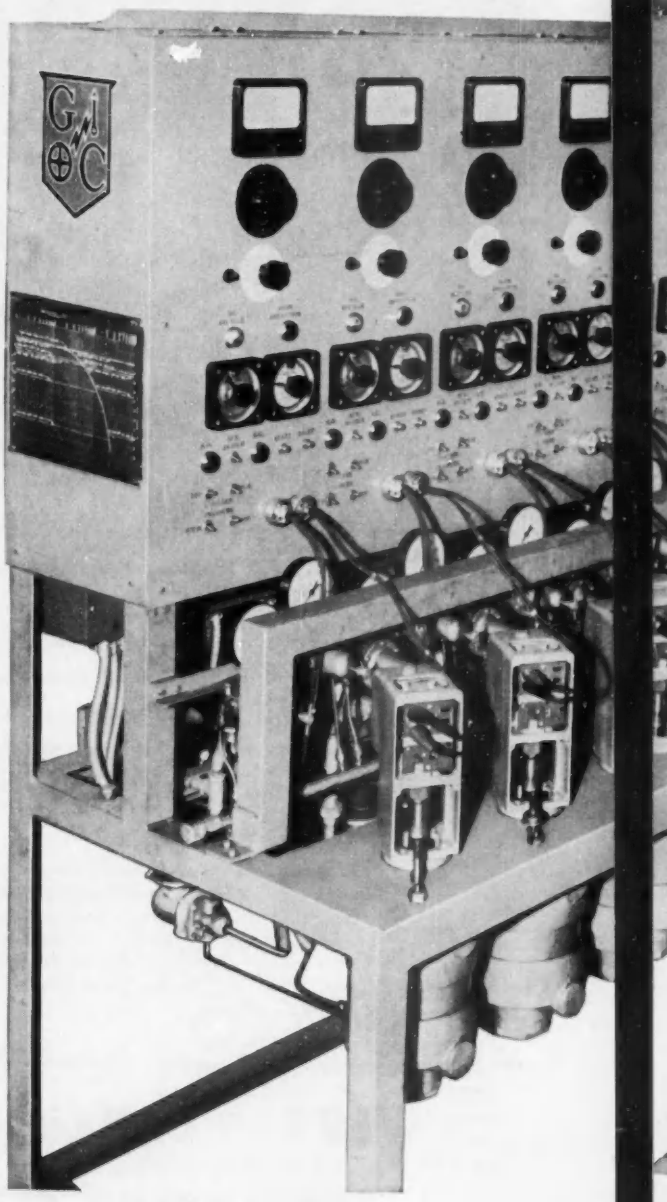
Two years of perfect performance prove how General Controls solenoid valves and pressure regulators provide low cost... reliable pneumatic test bench set-up

PROBLEM: To speed production output and increase economy, test engineer needed rugged, reliable pneumatic test set-up to vary pressure, provide selective load... simple controls, easy-to-read dials for one bench man to operate... up to 10 stations.

SOLUTION: Test engineer called in General Controls field representative who quickly devised a simple combination. A total of 40 two-way and three-way large capacity solenoid valves carry the load, and 20 pressure regulators with easy-to-read scales control the air flow.

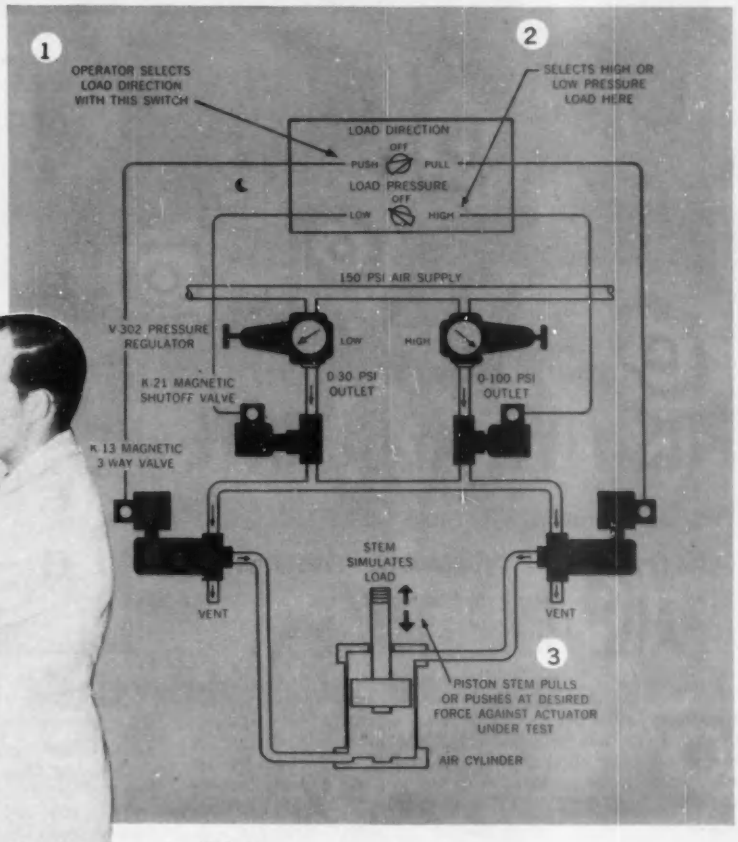
RESULT: Test bench has been operating on a heavy production schedule *for over two years without a failure!* No maintenance... lower labor cost... and increased output spell real economy!

NEXT TIME YOU have a control problem, remember that General Controls specializes in automatic controls that do the *whole* job better, more dependably. General Controls is a single source you can rely on... backed by a factory-trained field organization to provide skilled engineering counsel.

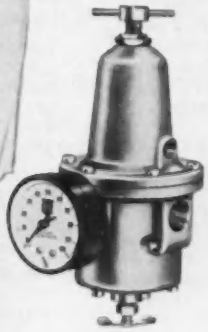


Call your nearby General Controls branch office.
Or write for a complete catalog:
GENERAL CONTROLS,
Dept. 400-F Glendale 1, Calif.

SOLVES TEST BENCH PROBLEM



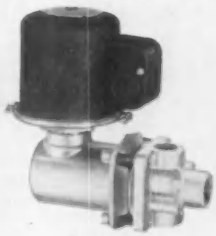




V-302
Pressure
Regulator



K-21
Solenoid
Shutoff Valve



K-13
Three-way
Solenoid Valve

GENERAL CONTROLS

America's Finest Automatic Controls for Home, Industry, and the Military

Glendale, California • Skokie, Illinois

Five Plants — 40 factory branch offices serving the United States and Canada



MICROAMMETER-MILLIVOLTMETER RECORDER PERFORMS 6 FUNCTIONS

1. **Measures low-level dc signals with calibration accuracy within 0.5%, and sensitivity within 0.2% of span.**
2. **Records on 3" continuous strip chart or IBM-type card chart, with linear coordinates.**
3. **Positions recording pen with force many thousand times greater than usual direct-deflection electrical movements.**
4. **Operates on force-balance principle—compensates for ambient conditions, changes in power supply and components.**
5. **Records fast—up to 0.05 seconds for 63% of fullscale changes.**
6. **Provides span and zero adjustments for easy calibration and zero suppression in the field, without special equipment.**

Here's How To Get POSITIVE, ACCURATE Records of Electrical Measurements ALL THE TIME...

This highly sensitive 'American-Microsen' Series 130 Recorder, with all its operational advantages, costs less than others designed for the same jobs. Simple design, precision components and rugged construction assure sustained high accuracy and freedom from maintenance. The recorder withstands shock up to 30 times gravity.

Since its introduction less than a year ago, the Series 130 Recorder has been very successful because it offers a more accurate and durable method of recording dc electrical signals at lower cost. It is being used to record outputs of many different electrical transducers – for measurement of such variables as pH, gas analysis, signal strength and others.

Many laboratories have adapted the Series 130 Recorder to their analytical and scientific instruments to assure accurate, permanent records of results which previously were only indicated. The Recorder can be used with any device which can provide 200 microamperes or more in its output circuit.

Standard 'American-Microsen' Series 130 Recorders are priced at $250.00. All models have ample power to operate alarm contacts which can be supplied at extra cost. *Write for Bulletin MG10.*

SPECIFICATION BRIEFS

POWER SUPPLY: 115 volts, 60 cycles. **POWER REQUIREMENT:** 9 watts.

INPUT RANGES: Voltage – 0-20 millivolts to 0-100 volts dc. **Current** – 0-200 microamperes to 0-100 milliamperes dc. **Input Sensitivity** – 6700 ohms per volts.

ACCURACY: ± 0.5% of span. **SENSITIVITY:** ± 0.2% of span. **REPEATABILITY:** ± 0.25% of span.

EFFECT OF SUPPLY VOLTAGE: Less than 0.5% error 90-130 volts.

EFFECT OF AMBIENT TEMPERATURE: Less than 0.5% error 50° to 100° F., and less than 1% to 130° F.

RESPONSE TIME: Fast Speed – 0.2 seconds standard for 63% of fullscale input change; up to 0.05 seconds for 63% on special order. **Slow Speed**– approximately 4 times fast speed setting.

CHART SPEEDS: Strip Chart – 1" per hr., standard; 3" or 6" per hr. available. **Card Chart** – 1 rotation per day, standard.

SPAN ADJUSTMENT: ± 10% of span. **ZERO ADJUSTMENT:** ± 100% of span.

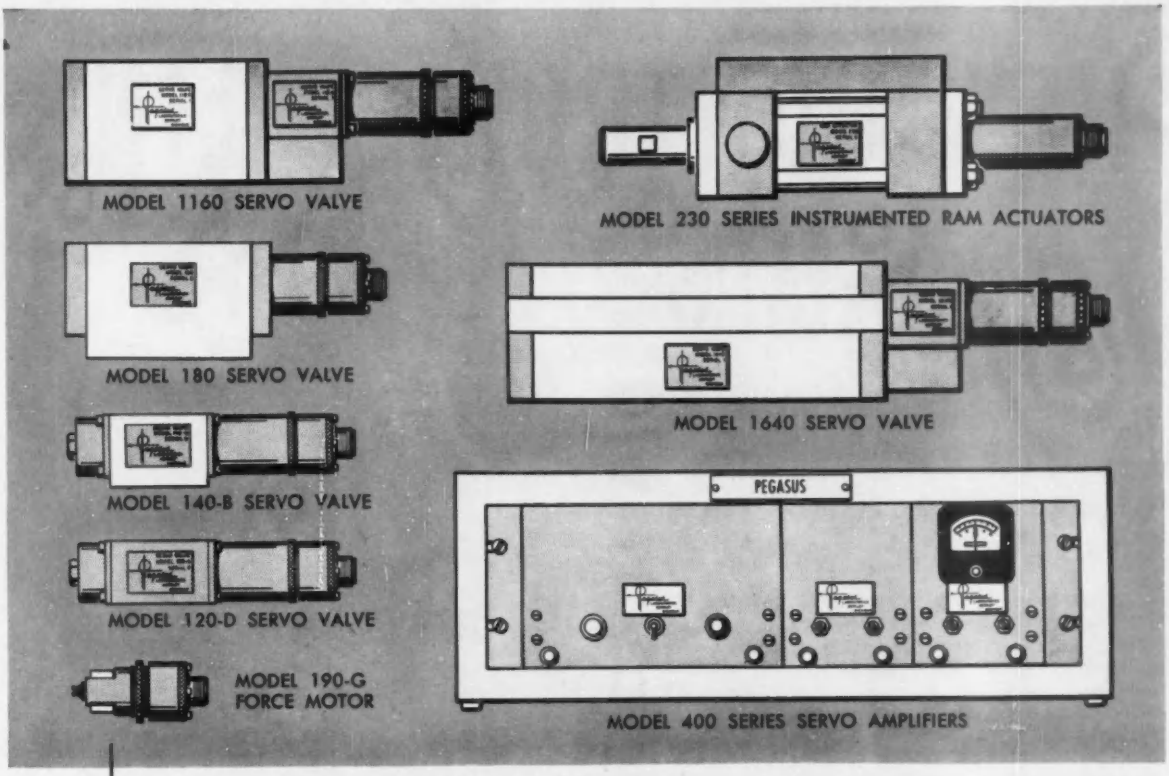
PANEL SPACE REQUIRED: Only 27 square inches.

MANNING, MAXWELL & MOORE, INC.

MAXWELL MANNING M&M & MOORE INC. TRADE MARK

INDUSTRIAL CONTROLS DIVISION • STRATFORD, CONNECTICUT

MAKERS OF 'AMERICAN-MICROSEN' ELECTRONIC TRANSMITTERS, INDICATORS, RECORDERS, CONTROLLERS, ELECTRO-PNEUMATIC VALVE POSITIONERS AND ELECTRO-HYDRAULIC CONTROL VALVE OPERATORS.



PEGASUS offers industry a complete line of high performance Electro-Hydraulic Servo Equipment

SERVO VALVES cover flow rates from 5 to 160 G.P.M., with natural frequencies from 50 to 200 c.p.s. closed loop. Concentration on long life and maximum dependability has been made throughout design and manufacture.

RAM ACTUATORS have feedback instrumentation mounted concentrically within the ram shaft. Strokes from 1 to 10 inches and areas from .5 to 5 square inches are available. Precision manufacture and double end seals insure minimum friction and long, leakage free operation.

SERVO AMPLIFIERS are of plug-in, modular construction, and include power amplifiers, power supplies, transformer demodulators, stabilized D.C. amplifiers, and other units required for your electro-hydraulic servo loops.

STANDARD ELECTRO-HYDRAULIC SERVO-MECHANISMS are designed and tested to your performance and load requirements, and are checked out at your plant by our application engineers.

SPECIAL COMPONENTS AND SYSTEMS are quoted where performance or production problems require some specific design.

Write us specifying your component or system problems, and we shall be pleased to submit our quotation.

PEGASUS LABORATORIES, INC.

DESIGNERS AND MANUFACTURERS OF ELECTRO-HYDRAULIC SERVOMECHANISMS

3690 W. ELEVEN MILE ROAD • BERKLEY, MICHIGAN

NEW CONTROLLER LINE ADAPTS 576 WAYS

Fenwal Announces Low-Cost Temperature Indicating Controllers

ASHLAND, MASS. — Fenwal Inc., has announced here that tailor-made, accurate, low-cost temperature indicating controllers are now available from stock.

Tailor-mades from stock are made possible by the development of the new Fenwal Series 541 line. The Series 541 is a standardized line of matched temperature indicating controller parts which can be combined easily in 576 ways.

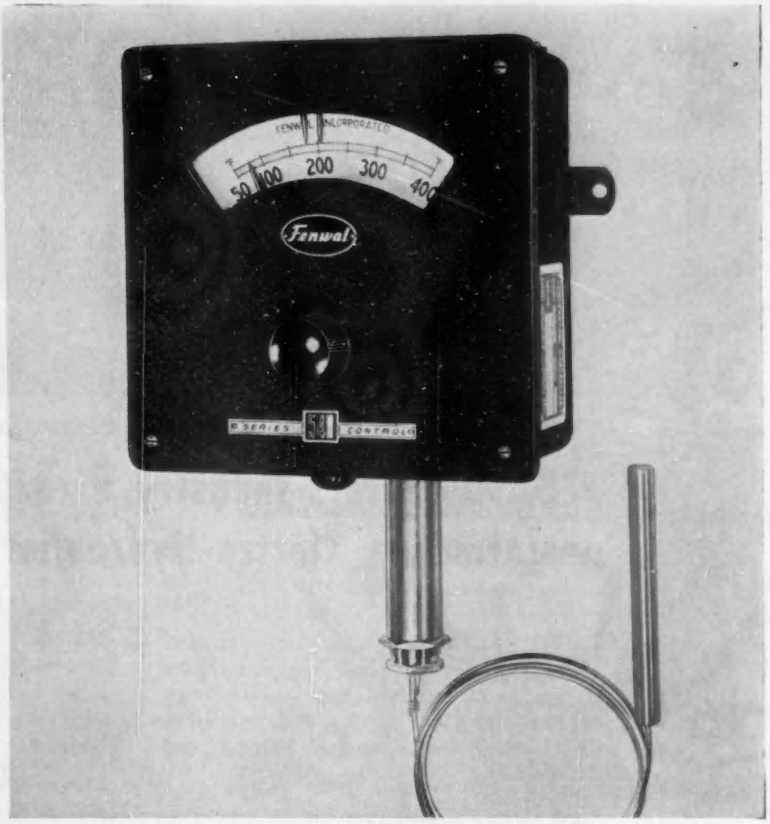
From these possible combinations come perfect solutions to countless temperature control problems. A prospective user lists the characteristics of the ideal temperature indicating controller for his particular operation, and Fenwal assembles an instrument with those characteristics from parts in stock.

No matter what combination is chosen, the result is a rugged, accurate, compact and easily maintained unit in a shock-proof, splash-proof, dust-proof housing. The housing is available in colors to match any equipment in which it may be installed.

Installation and calibration are so simple that instrument technicians and laboratory procedures are unnecessary. And, after installation, all normal temperature adjustments are external.

No matter what combination is chosen, the resulting instrument is accurate to within one per cent of scale. The accuracy is long lasting, with few moving parts and no internal gears. Simplicity of design brings the wear factor close to zero.

Series 541 offers single or double circuit control. There is a choice of four different long-life snap switches, with ratings up to 20 amps, 250 volts, A.C. These switches, singly or in combination, can provide a wide variety of operating characteristics.



One of Fenwal's new Series 541, bulb-and-capillary controllers. Photo shows dual circuit model which has two snap switches, each with a setpoint indicator, that actuate two separate circuits at the pre-set temperatures.

Three stainless steel bulb types are available at no increase in price to meet space or process requirements. Capillaries and bulbs are corrosion-proof. Capillaries are swivel-mounted to protect them from breakage.

There is a choice of three temperature ranges: −150° to 200°F, 50° to 400°F, or 50° to 700°F, or their centigrade equivalents. Special ranges are available on request.

The control mechanism may be subjected to temperatures up to 150°F, and is ambient compensated from 50° to 150°F.

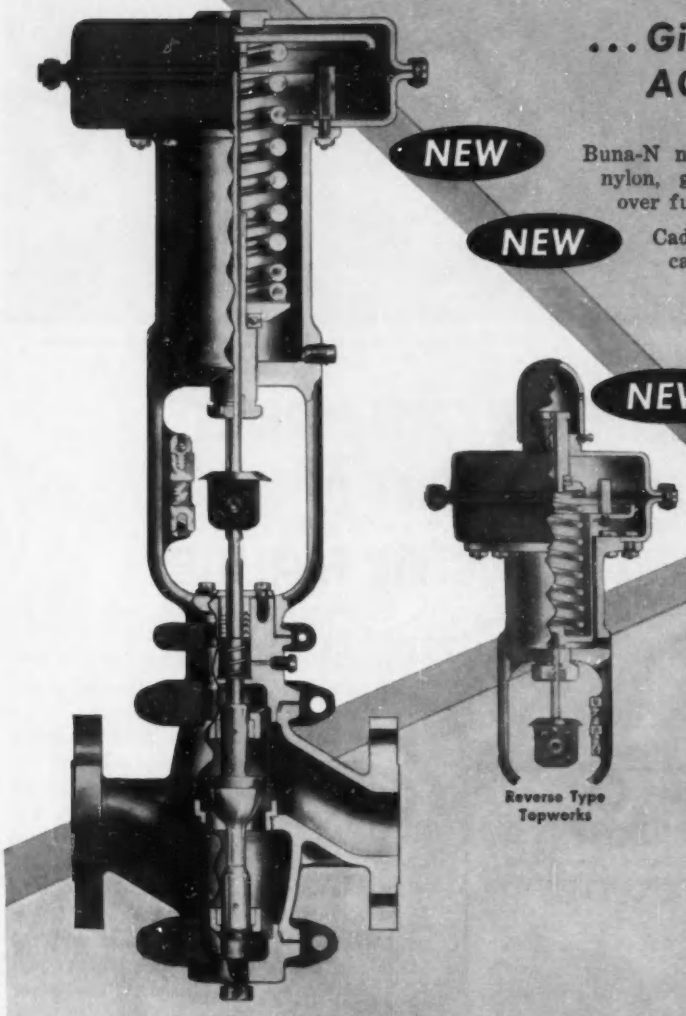
Write to Fenwal Incorporated, 594 Pleasant Street, Ashland, Mass. Describe the tailor-made temperature indicating controller that would fit your operation perfectly. Chances are excellent that the tailor-made can be yours — at savings never before possible.

Fenwal

CONTROLS TEMPERATURE
. . . PRECISELY

New BS&B Super 70 series TOPWORKS

...Give FAST, ACCURATE Response!



Reverse Type Topworks

NEW Buna-N moulded diaphragm, reinforced with nylon, gives uniform cross sectional thrust over full valve travel.

NEW Cadmium plated pressed steel diaphragm cases give maximum strength and corrosion resistance with minimum weight. Special chromate treatment provides superior bonding agent for paint and added corrosion protection.

NEW Bolted clamp ring device integrates body and topworks assemblies into a single unit, and permits yoke to be oriented to any convenient position for observation and action.

Four sizes of Super 70 Series Topworks are available in both direct and reverse acting types. Both are interchangeable on single port, double port, or split body styles. A single spring, precision calibrated to plus or minus 2% of rating, provides accurate travel response to changes in diaphragm loading pressure. (Reverse type topworks uses recessed spring). Ductile iron yoke provides the rigidity of cast iron and the safety of steel. All units use split and bolted stem connector and adjustable travel scale plate.

This advertisement highlights only features of the Super 70 Series Topworks. For information on the new valve bodies of the Super 70 Series line, ask for Catalog 70-11.

EFFICIENCY OVER 60 YEARS BS&B RELIABILITY
ANOTHER EXAMPLE OF PRODUCT LEADERSHIP

BLACK, SIVALLS & BRYSON, INC.

Controls Division, Dept. 4-ES4

7500 East 12th Street Kansas City 26, Missouri



Section of department making stators for Bendix synchros and motors



SHOP AT THE BENDIX "SUPERMARKET" TO TAKE ADVANTAGE OF MASS SYNCHRO PRODUCTION FACILITIES

EXTERNAL SLIP RING AUTOSYNS®

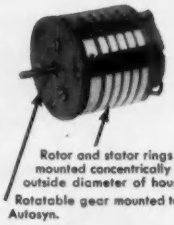
Bendix external slip rings replace ordinary fixed leads where it is desired to rotate the stator in addition to, or instead of, the rotor. Individual mechanical and electrical requirements determine location and configuration of these external rings.

As can be seen from the few examples below, many variations are possible in Bendix External Slip Ring Autosyns.



Three external stator rings in face of Autosyn.

Two external rotor rings.



Rotor and stator rings mounted concentrically with outside diameter of housing.

Rotatable gear mounted to Autosyn.



Rotor and stator take-offs are by means of brushes riding on these external rings.

Fast delivery of practically any type synchro at minimum cost. Isn't that what you want from your synchro supplier?

If so, consider how well Bendix fills the bill. First, as a virtual "supermarket" for synchros, we maintain mass production that means minimum unit prices, even to small-quantity buyers. Second, we produce virtually all types of synchros as *standard items,* meaning you can get delivery fast *—immediately,* in most cases.

Finally, Bendix synchros are built to exacting precision standards that equal . . . or exceed . . . those of any other synchros made.

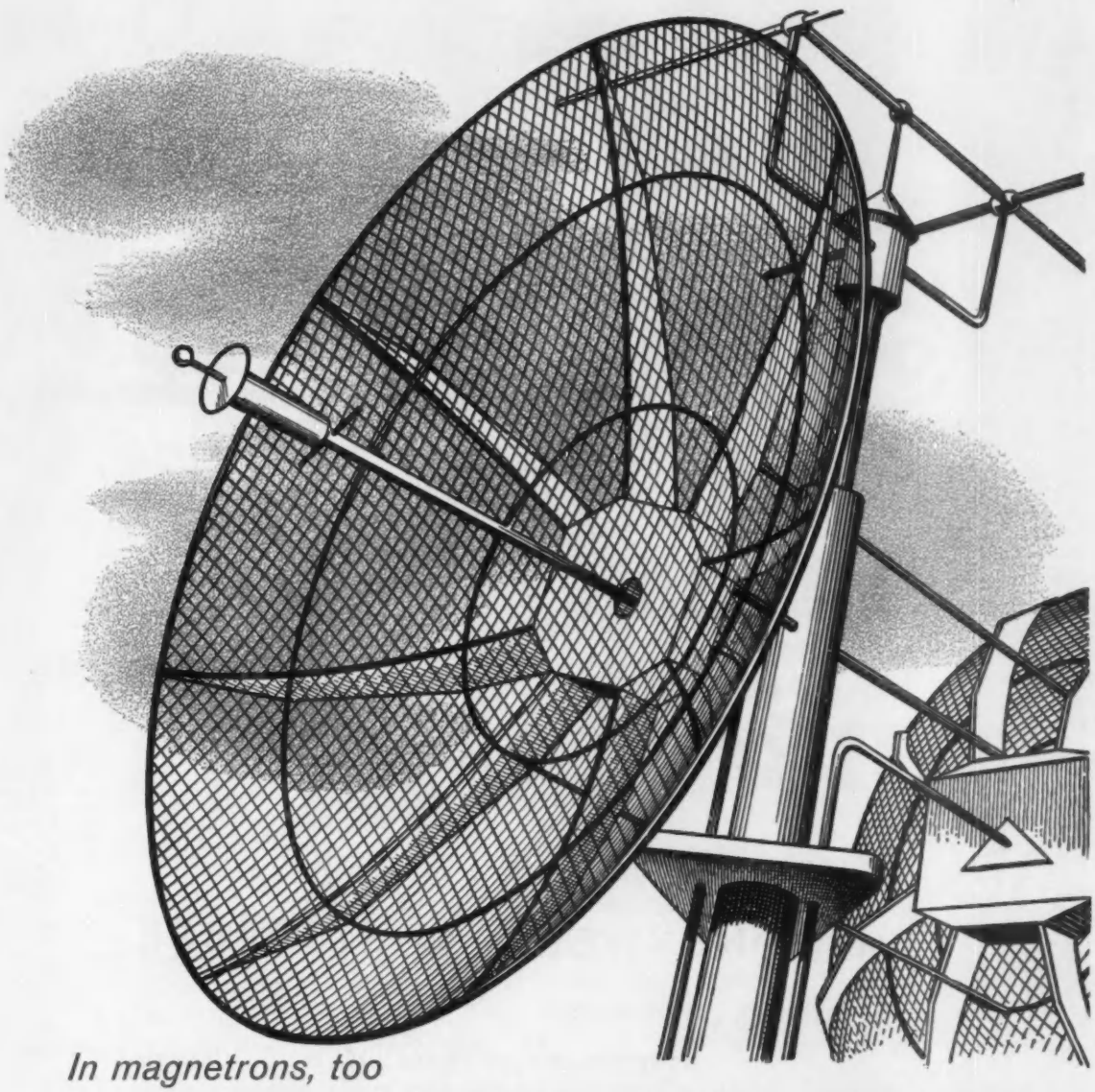
Let our vast experience and mass production facilities go to work on *your* synchro needs, too!

District Offices: Burbank, Calif., Dayton, Ohio, Seattle, Wash.
Export Sales and Service: Bendix International Division, 205 E. 42nd St., New York 17, N. Y

Eclipse-Pioneer Division

Teterboro, N. J.

Bendix
AVIATION CORPORATION



In magnetrons, too

CRUCIBLE PERMANENT MAGNETS

provide maximum energy... minimum size

In designing magnetrons for radar systems —or any very high-frequency oscillator application—you can be sure of a *consistently higher* energy product with Crucible alnico magnets. ***This means more power from a minimum size magnet!***

Crucible alnico permanent magnets are made to meet practically any size requirement from a fraction of an ounce to several hundred pounds. And they're sand cast, shell molded or investment cast to the exact size, shape, tolerance and finish you need.

Crucible has been one of the largest producers of permanent magnets since the development of alnico alloys. Its unsurpassed magnet experience is backed by over 50 years of fine steelmaking. That's why the best solution to magnet problems starts with a call to Crucible. *Crucible Steel Company of America, Henry W. Oliver Building, Pittsburgh 22, Pa.*

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America

all
at
once...

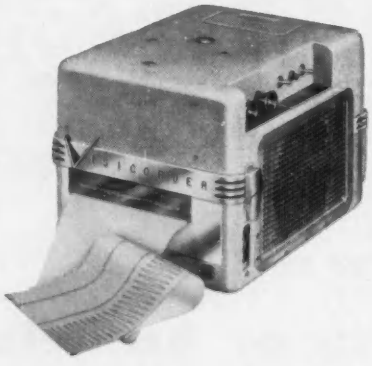


the HONEYWELL VISICORDER

directly records six phenomena
at frequencies from DC to 2,000 cps

The versatile Visicorder will fit almost unlimited oscillograph applications where instantaneous monitoring and direct recording at high frequencies are needed.

The Visicorder is the only oscillograph that records directly at frequencies up to 2,000 cps, and at sensitivities comparable to photographic-type oscillographs. No peaked amplifiers or other compensation of any kind are needed. The record requires no liquids, vapors, powder magazines or other processing materials.



Deflection is six inches peak to peak, covering the full width of the chart. The D'Arsonval-movement mirror galvanometers, in your choice of natural frequencies will, of course, overlap their traces; they are not limited by adjacent channels.

Let your nearest Honeywell Industrial Sales Engineer tell you more about how the Visicorder fits *your* application. Call him today.

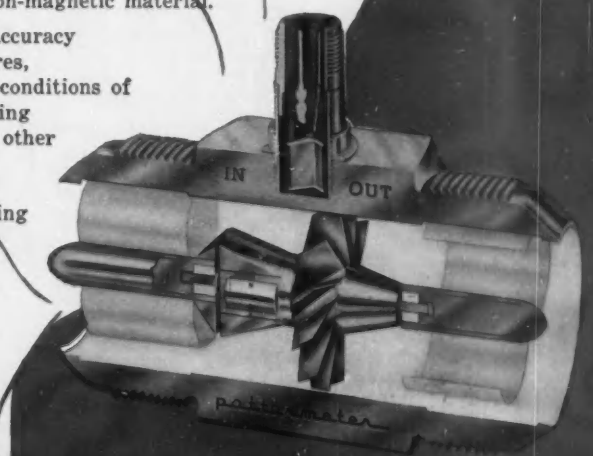
MINNEAPOLIS
Honeywell
HEILAND INSTRUMENTS
5200 EAST EVANS AVENUE • DENVER 22, COLORADO

Perfect performance by POTTERMETER

POTTER Flow Control Systems are currently operating at temperatures as low as —455°F. and as high as 1000°F., at pressures up to 35,000 psi—with no ceiling.

The POTTERMETER Flow Sensing Element, is based on a unique venturi design with a *bearingless*, hydraulically-positioned rotor, and can be made of stainless steel or any non-magnetic material.

POTTER systems feature high accuracy over a wide range of temperatures, pressures, density and viscosity conditions of liquids and liquefied gases, including acids, caustics, hydrocarbons and other corrosives. They are shock and vibration-resistant and can be utilized with a variety of indicating totalizing, recording and/or control instrumentation.



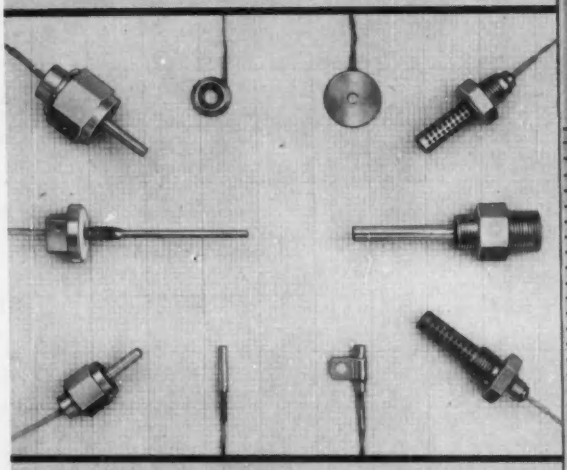
Only POTTER makes the POTTERMETER

Write TODAY for Bulletin T1

POTTER

POTTER AERONAUTICAL CORP.
U. S. Route 22, Union, New Jersey
MUrdock 6-3010

For the highest degree of *Accuracy* in AIRBORNE TEMPERATURE INSTRUMENTATION



HIGH OUTPUT • RESISTANCE-TYPE TRANSDUCERS

Arnoux high resistance temperature probes are designed for telemetering and other applications requiring high signal levels. Models are available in a wide variety of physical configurations for measuring surface, fluid, and air temperatures.

- Output up to 5 volts without amplification.
- −320°F to +500°F range with ±2% linearity. (Special units are available up to 1600°F.)
- Nominal resistance values: 100 to 20,000 ohms.
- May be used in AC or DC Bridge circuits.
- Meets MIL-E-5272A specifications.
- Calibration curve supplied with each probe.

When used with ARNOUX miniaturized companion "TME" system, 20K transducers provide 5 volts output for as little as 150°F change.

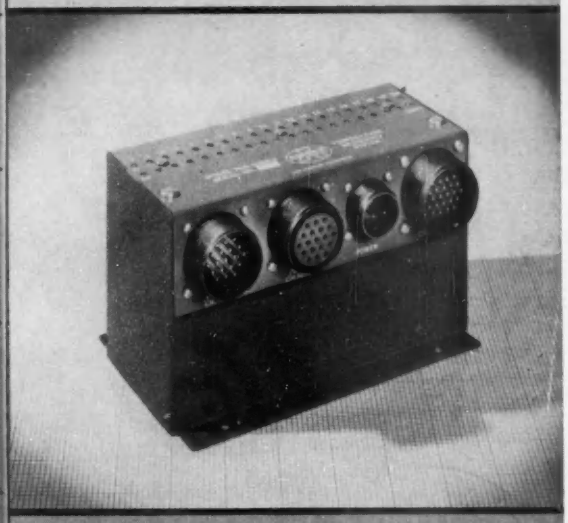
Write for Bulletin 300

MINIATURE MULTI-CHANNEL TEMPERATURE MEASUREMENT SYSTEM... full scale output 5 volts

ARNOUX "TME" is a completely self-contained system designed for operation with ARNOUX special resistance-type transducers. Models are offered in 7, 14, and 20 channel capacity. The unit contains two precision mag-amp type, regulated D.C. power supplies, series connected with common neutral, for excitation of the transducers in half bridge circuitry.

- Power requirement: 115 volts, 400 cps.
- Power consumption: 20 channel model requires less than 20 watts.
- Balance and attenuation controls for each channel.
- No vacuum tubes or transistors used.
- Output voltage and impedance characteristics — directly compatible with F.M. sub-carrier and P.W.M. coder input requirements.
- System stability: within 1% throughout MIL-E-5272A environmental.
- Dimensions: 20 channel model: 7" x 4¼" x 3", wt. 5½ lbs.

Write for Bulletin 500



ARNOUX... *foremost* **in TEMPERATURE MEASUREMENT EQUIPMENT... ...TRANSDUCERS, ACCESSORIES AND CUSTOM ENGINEERED SYSTEMS.**

ARNOUX CORPORATION

Designers and Manufacturers of Precision Instrumentation

11924 W. WASHINGTON BOULEVARD • LOS ANGELES 66, CALIFORNIA

NOW-PORTABLE
400 cycle power

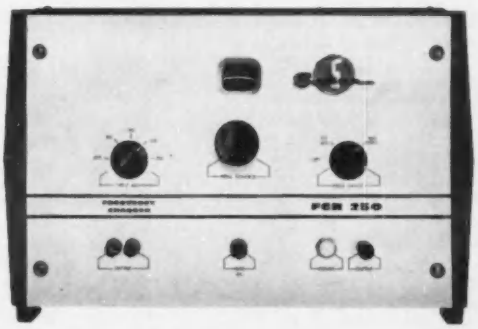


This new frequency changer makes it possible to provide well regulated 400 cycle power conveniently and quickly. This unit, Model FCR 250, is extremely useful in a wide variety of applications including testing, production, airborne frequency control, computers, missile guidance system testing, and in practically any application where the use of 400 cycle power is advantageous.

Model FCR 250 is only one of a complete line of frequency changers available from Sorensen . . . the authority on controlled power for research and industry. Write for complete information.

ELECTRICAL CHARACTERISTICS

Input	105-125 VAC, 1 phase, 50-65 cycles
Output voltage	115 VAC, adjustable 105-125V
Output Frequency	320-1000 cps in two ranges
Voltage regulation	±1%
Frequency regulation	±1% (±0.01% with auxiliary frequency standard fixed at 400 cycles)
Load range	0-250 VA



MODEL FCR 250

SORENSEN & COMPANY, INC. Sorensen STAMFORD • CONN.

In Europe, contact Sorensen-Ardag, Eichstrasse 29, Zurich, Switzerland, for all products including 50 cycle, 220 volt equipment.

From Electro Instruments comes a revolutionary new concept in digital instrumentation.

transistorized, plug-in modules for precision measurements of dc, ac, ohms and ratios

NOW GET MAXIMUM FLEXIBILITY FOR CUSTOM APPLICATIONS WITH STANDARD, OFF-THE-SHELF MODULES

Check these new specifications and features—the result of thousands of applications and field experience of more than 1,000 digital instruments

Fully transistorized circuits in the new modules provide

1. Increased reliability.
2. Reduced power consumption.
3. Low heat dissipation.
4. Miniaturized packages.
5. Elimination of radio noise and line transients.

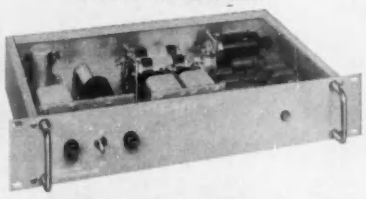
New specifications and features

1. Wider dynamic range covering all voltages from **100 microvolts to 1,000 volts,** resistance range from **10 milliohms to 10 megohms**—in **single** instruments!
2. Input power frequencies from **50 to 400 cycles!**
3. New balance logic speeds down ranging!
4. Automatic ac ranging from 30 to 10,000 cycles!
5. Controlled stepping switch drive increases switch life by a factor of **three!**

Complete flexibility

1. Universal 3½" x 19" x 12" chassis with mounting hardware for any rack.
2. No modifications required for operating printers, IBM Punches, etc., or for combining with auxiliary E-I input modules or instruments.
3. All contacts readily accessible at rear panel on connectors.
4. With auxiliary plug-in modules, digitized data is provided in printed form, punched cards or tape with no modification to basic measuring instruments.

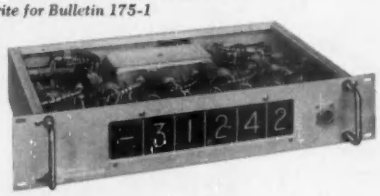
BASIC MODULES



Universal Power Module, Models DXA-000 or DXB-000

Supplies *all* power and reference voltages for other E-I modules. Power and reference supplies and stepper drive amplifier are transistorized. Powers one or more modules.

Calibration: Automatic
Reference Stability: 0.01% from 40° to 125° F.
Input Power: 115 volts, 50 to 400 cycles.
Write for Bulletin 175-1



DC Switch Module
Model DVX-400: 4 digits; **Model DVX-500:** 5 digits

Contains Digital Potentiometer. Provides visual in-line read-out of digits, polarity, decimal point. All contacts accessible at rear panel connector. Front and rear panel input connectors. Power supplied by Universal Power Module.
Write for Bulletin 175-2



DC Pre-Amp Module, Model DXX-020

Input: 1 range scale, gain of 10.
Output: 0.0001 to .9999 volts. **Linearity:** 0.01%.
Gain Multiplication Accuracy: 0.01%.
Input Power: 115 volt, 50 to 400 cycles.
Drift: 10 microvolts per hour.
Write for Bulletin 175-5



AC-DC Converter Module, Model DXX-010

A fully transistorized AC-DC converter.

Accuracy: 0.1% of reading, or 2 mv.
Frequency Response: 30 to 10,000 cycles.
Range: .0001 to 999.9 volts.
Zin, AC: 1 meg. on the 1 volt scale, 10 megs. on other scales; 20 mmf.
Ranging: Automatic. **Reading time:** 3 seconds, average.
Write for Bulletin 175-4



Resistance Switch Module
Model DOX-400: 4 digits; **Model DOX-500:** 5 digits

Contains balance circuit, bridge ratio arms. Provides visual in-line read-out of digits, range. All contacts accessible at rear panel connector. Power supplied by Universal Power Module.
Write for Bulletin 175-3

Using E-I's new, transistorized, modular design, any precision instrument for measuring DC, AC-DC, Ohms, DC and AC ratios can be constructed from basic units!

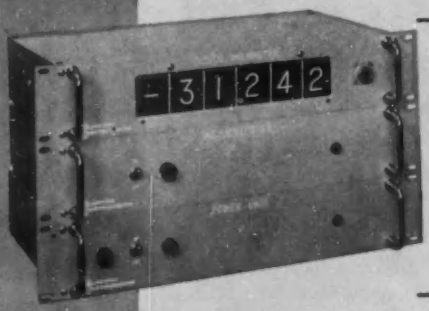


DC Digital Voltmeters

specifications	**Model DVA-400** (Combines Universal Power Supply, Model DXA-000, and Model DVX-400 Modules.)	**Model DVA-500** (Combines Universal Power Supply, Model DXA-000, and Model DVX-500 Modules.)
Display:	4 digits, plus or minus, decimal point.	5 digits, plus or minus, decimal point.
Accuracy:	±1 digit.	±0.01%, plus or minus 1 digit.
Range:	.0001 to 999.9.	0.0001 to 999.99.
Automatic Features:	Ranging, polarity.	Ranging, polarity.

(Adding the E-I Pre-Amp Module, Model DXX-020, increases sensitivity to 10 microvolts.)

DC RATIOMETER – Same modules as Voltmeter except uses external reference. Ratio range: 0.0000 to 1.0999.



AC-DC Digital Voltmeters

specifications	Model DVA-410	Model DVA-510
DC Specifications:	Same as Model DVA-400.	Same as Model DVA-500.
AC Specifications:	Same as Model DXX-010.	Same as Model DXX-010.

(AC RATIOMETER combines Model DVA-400, with two Model DDX-040 or Model DXX-050 Modules. Ratio range is 0.0000 to 1.0999.)



Digital Ohmmeter

specifications	Model DOA-400 (Combines Model DXA-000 and DOX-400 Modules.)	Model DOA-500 (Combines Model DXA-000 and DOX-500 Modules.)
Display:	4 digits.	5 digits.
Range:	Automatic, 0.01 ohms to 10 megohms.	Automatic, 0.01 ohms to 10 megohms.
Accuracy:	0.01 to 0.1%.	0.01 to 0.1%.



OPERATING MACHINE READ-OUTS

Pictured here is a typical Automation System constructed with standard E-I modules. This system automatically scans and measures 400 channels of AC and DC voltages with punched tape read-out. E-I Model 200 X-Y Recorder provides plotted data. With auxiliary plug-in input and output modules, complete custom data handling systems may be set up. Write for Bulletin 175-6.

NEW HAND-CARRY MODEL

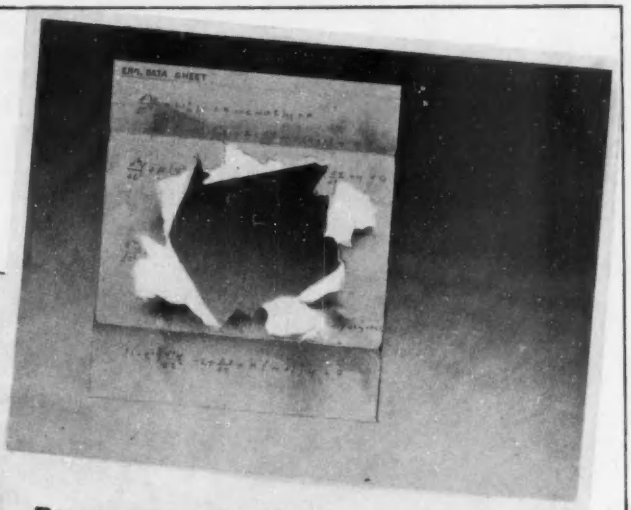
The Mark IV is the ideal companion to the new E-I rack-mounted modular equipment. Compact, weighs only 25 lbs.; 0.05% accuracy. Write for Bulletin 170.



ELECTRO INSTRUMENTS

INC. 3794 Rosecrans, San Diego, California

NEW LITERATURE AVAILABLE—Write for new short form Bulletin 175 containing information about the new Electro Instruments modular design.





NOW! AUTOMATIC NAVIGATION FOR GLOBAL JET FLIGHT

An advanced system of aerial navigation, with the speed and precision demanded by high speed jet flight, has been developed by Ryan under sponsorship of the Navy's Bureau of Aeronautics. Using continuous-wave radar, in which Ryan is a recognized leader, the Ryan AN/APN-67 navigator will enable fast-flying military planes and future commercial jetliners to travel to any point on the earth's surface with new accuracy and speed.

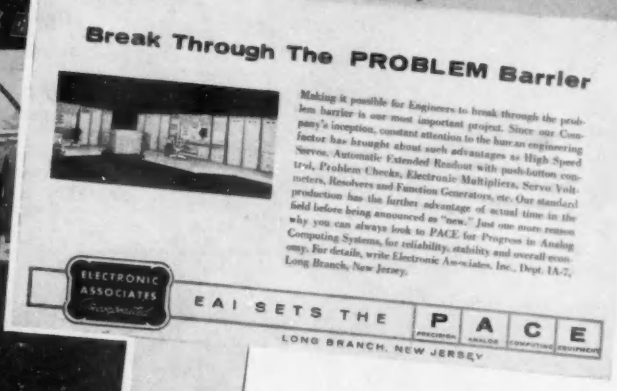
Instantaneous in operation, the Ryan navigator gives the pilot his position (latitude and longitude), ground speed, ground mileage, drift angle and ground track in continuous, readable form. No computations are necessary. The equipment is compact and self-contained. No ground facilities are employed—no wind information or aerological data are needed.

This significant contribution to jet navigation is typical of the work which Ryan and the military services are accomplishing in other fields of electronics research such as supersonic missile guidance for the Air Force and helicopter hovering devices for the Navy.

Electronics engineers will find a challenging future with outstanding opportunities at Ryan

With a background of 23 years experience in aviation, Ryan excels in designing and producing high quality aircraft, power plants and avionics, built at low cost, delivered on time.

RYAN



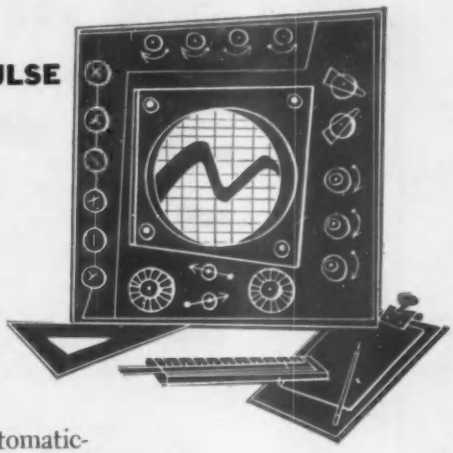
The decision is precision . . . .
. . . . as it was with Ryan Aeronautical Company.

That is why Ryan selected Electronic Associates' PACE Analog Computing Equipment to help them break through the problem barrier. 1) EAI'S PACE Equipment provides highest accuracy. 2) EAI sets the PACE for reliability and versatility. 3) EAI's unique and economical building block method provides for your future as well as present problem barriers. Contact our Computation Centers for a demonstration or for rental of time. There's a Center serving Eastern Industry in Princeton, N. J.—one serving Western Industry in Los Angeles, Calif. For equipment information, write Electronic Associates, Inc., Long Branch, New Jersey Dept. CE-4.

ELECTRONIC ASSOCIATES Incorporated

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Instrument Makers Set the Pace in R&D

Several things about the makers of instruments and automatic-control equipment suggest that this industry funnels an unusual amount of dollars into research and development. For one thing, there is its emphasis on new products: *Pulse* for March '55 estimated that most control makers create three completely new items each year. Another is its unusual number of engineers: some firms have almost a 1:1 ratio between production and technical people. And a third is the terribly sparse profit margin maintained—a sure sign of unusual overhead in R&D.

3 R&D causes . . . . . or effects?

Late last year a superb means appeared for checking our theory: a 118-page report by the Bureau of Labor Statistics for the National Science Foundation on the R&D expenditures and habits of over 10,000 industrial organizations. Prominent in the tabulation are data from 500 "professional and scientific instrument" makers—the SIC breakdown of the so-called instrument industry (see *Pulse*, July '56, page 61). Granted that there is much this SIC category does not include, it is still by far the clearest picture of instrument-maker practice we have to date: it provides an assay of how and how much these companies spend on R&D, what kind of R&D they do with what kind of talent, and what kind of payoff they get in patents.

How big are the instrument makers that do R&D, and where do they get their funds to do this work? In 1953, of the 500 instrument makers conducting R&D, 350 had less than 100 employees, 90 had 100-499, 20 had 500-999, 32 had 1,000-4,999, and less than 10 had 5,000 or more. As a group these firms spent $171.7 million on R&D in that year—roughly 4.6 percent of the national total. In contrast to the aircraft makers, which used 6 government dollars for every company dollar in R&D, the instrument industry relied heavily on its own funds: only $76.8 million was tied in with Federal contracts. Most of the instrument makers did their R&D inside their own plants.

Average maker is a small one

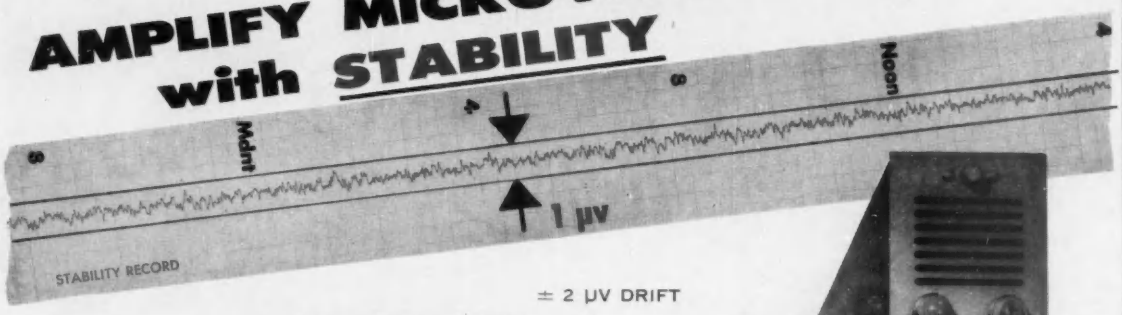
How does the instrument maker's R&D stack up against other industries? Very well, indeed. For one thing the industry leads all others in company-invested nonmilitary R&D as a percentage of sales (almost 3 percent in '53). However, it tags behind aircraft and electrical equipment makers in total R&D costs per sales dollar because of the huge support these two industries get from government contracts. Another point for the instrument maker: the 500 firms lead all others in the amount of research funds invested as a percent of a company's

Spend the most for nonmilitary R&D

KINTEL
[KAY LAB]

FOR DRIFT-FREE DC INSTRUMENTATION

AMPLIFY MICROVOLTS with STABILITY



± 2 μV DRIFT

INTEGRAL POWER SUPPLY

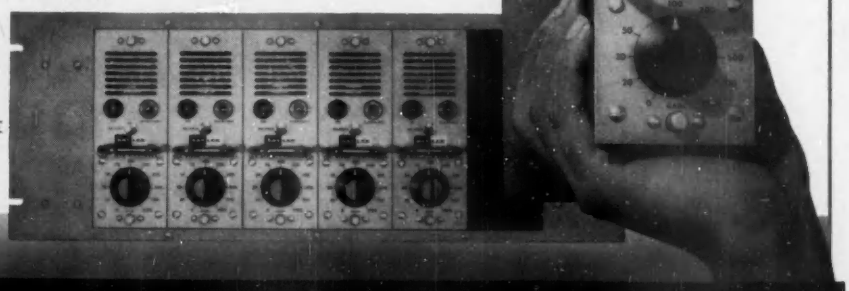
HIGH OUTPUT LEVEL

EXTREMELY LOW NOISE

BROAD BANDWIDTH

10 ACCURATE GAIN RANGES

HIGH INPUT IMPEDANCE



The **KINTEL** Model 111 amplifier provides maximum stability and the lowest drift of any commercially available broadband d-c amplifier. It is the end result of years of research in the field of chopper stabilized broadband d-c amplifiers. Thousands of **KINTEL** amplifiers are in daily use.

The Model 111 incorporates **KINTEL's** proven chopper amplifier circuitry and provides ten extremely precise, feedback controlled gain ranges. Several feedback loops assure high accuracy, stability and uniform frequency response. The completely new and unique circuit provides rapid recovery from severe overloading and unsurpassed dynamic performance—unaffected by load or gain changes.

The Model 111 is available in a single-unit cabinet or in a six-unit rack-mountable module. The amplifiers are extremely compact; the six-unit module occupies only a 19-inch rack width.

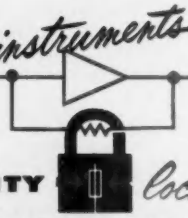
APPLICATIONS: The Model 111 is ideal for permanent low level d-c instrumentation, telemetering, or as a strain gage amplifier, transducer amplifier, scope preamplifier, recorder driver amplifier, or general purpose laboratory amplifier.

SPECIFICATIONS

Gain	0, 20, 30, 50, 70, 100, 200, 300, 500, 700, 1000
Gain Accuracy	± 1% DC to 2 KC
Input Impedance	100,000 Ω
Output Capability at DC	0 to ± 35 V where R_L > 1000 Ω 0 to ± 40 MA where R_L is 10 to 400 Ω
Output Impedance	Less than 1 Ω in series with 25 μh
Equivalent Input Drift	± 2 μv with regulated line
Equivalent Input Noise	0 to 3 cps, less than 5 μv peak to peak 0 to 750 cps, less than 5 μv RMS 0 to 50 kc, less than 12 μv RMS
Chopper Intermodulation	Less than 0.1%
Linearity	Better than 0.1% to 2 KC
Frequency Response	± 3% (0.3 db) DC to 10 KC, less than 3 db down at 40 KC

Power Requirements:	
Amplifier	117 V—60 cycles—70 VA
Cabinet	117 V—60 cycles—15 VA
6 Unit Rack Adaptor	117 V—60 cycles—45 VA
Dimensions: Amplifier Unit	2⅞" wide, 7⅞" high, 14⅝" deep
Rack Adaptor for 6 Units	19" wide, 8¾" high, 18¼" deep
Net Weight—Amplifier	11 pounds
PRICE: Amplifier Unit	$550.00
19-inch Rack Adaptor for 6 amplifier (with fans and connectors)	200.00
Cabinet for single amplifier (with fan and connector) is available.	

...the Standard in chopper-stabilized instruments



STABILITY *locked in!*
WITH CHOPPER AMPLIFIERS

KINTEL
[KAY LAB]

Representatives in all major cities.

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assets (almost 4 percent against a national average of 0.8 percent).

What kind of R&D does the instrument maker emphasize? The facts above suggest that he favors commercial over military projects. However, almost all of his work was done in applied research—only 6.8 percent of R&D cost went into basic investigations (as contrasted with 10.5 percent in the chemical field and almost 10 percent in ceramic products).

Engineers rule the roost

The kind of technical people doing R&D for the instrument maker also reveals the practical intent of this work. The 500 firms employed 18,800, divided as follows: 13,900 engineers, 1,900 chemists, 800 physicists, 200 metallurgists, 200 life scientists, only 100 mathematicians, and 1,700 others. It is interesting to note that the instrument makers were second only to the aircraft firms in the percentage of these technical people directly engaged in R&D (aircraft—56.9 percent; instrument makers—48.6 percent).

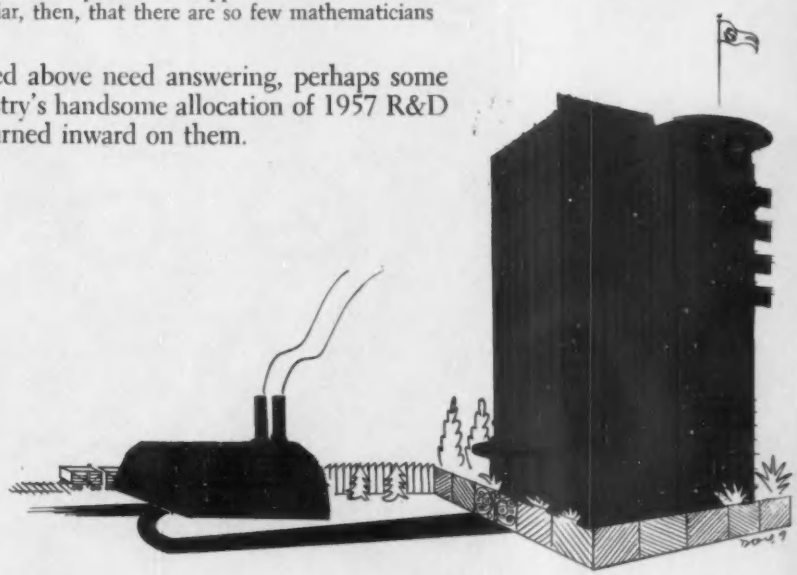
Big payoff in patents for R&D

Payoff for R&D is indicated by the survey's tabulation of patents owned and applied for by instrument makers in 1953: owned, 16,300; pending, 3,300. This total was exceeded only by the chemical, petroleum, machinery, and electrical equipment industries—and in all cases, with the exception of petroleum, the actual payoff per R&D dollar spent favored the instrument maker.

Rosy and dynamic as this picture may be, the facts and figures raise certain soul-searching questions:

- it's well known that instruments play a vital role in our defense complex—then why aren't more Government dollars enriching R&D programs of the (especially small) instrument makers?
- the figures show that R&D costs take up a formidable portion of instrument-maker sales income—does this mean that the pricing structure in this industry may be on the low side?
- applied research dominates the industry's R&D effort—is progress being curbed by this neglect of basic investigations?
- instruments are the tools for a *quantitative* approach in science and engineering—isn't it peculiar, then, that there are so few mathematicians working in this field?

If the questions posed above need answering, perhaps some of the instrument industry's handsome allocation of 1957 R&D dollars could well be turned inward on them.





"G-E SILICON Low Current RECTIFIERS cover the field from ¼ amp up to 18 amps† ... really stay on the job ... and *the price doesn't hurt*"

Every engineer who works with d-c power supplies for assemblies or components of moderate current demand finds a valuable source in the General Electric rectifier line. G-E Silicon Rectifiers—whether the Axial Lead or the Stud Mounting models in single cells, or in Stack assemblies with their remarkable range of current and voltage ratings—are part of our extensive range of rectifier or other semiconductor devices.

The table on output and performance figures only suggests the range of specifications available. For further data, or exact information on rectifiers for your specific needs, call your General Electric Semiconductor representative. Or write *General Electric Company, Semiconductor Products, Section S1647, Electronics Park, Syracuse, N. Y.*



STUD RECTIFIERS. Fit them in wherever you need maximum current and temperature in minimum space with rigid chassis mounting.



STACK INSTALLATION. A typical way of mounting General Electric Silicon Rectifier Stacks. Just two screws fasten the entire assembly in place.

REPRESENTATIVE G-E SILICON RECTIFIER RATINGS

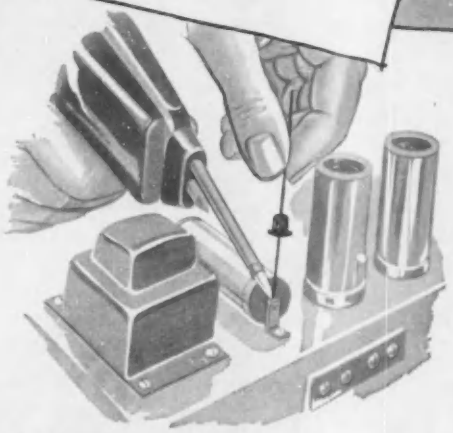
PIV	STUD*	LEAD**	STACKS***
50		1N536	4JA411F Series
100	1N1115	1N537	4JA411A Series
200	1N1116	1N538	4JA411B Series
300	1N1117	1N539	4JA411C Series
400	1N1118	1N540	4JA411D Series
NEW . . . Following is now in production			
500		1N1095	

***Maximum Current**— 600 ma @ 150°C Case Temperature
1500 ma @ 85°C Case Temperature

****Maximum Current**— 250 ma @ 150°C Ambient Temperature
750 ma @ 50°C Ambient Temperature

*****Maximum Current**— ½ amp per fin @ 150°C Ambient Temp.
1½ amp per fin @ 85°C Ambient Temp.

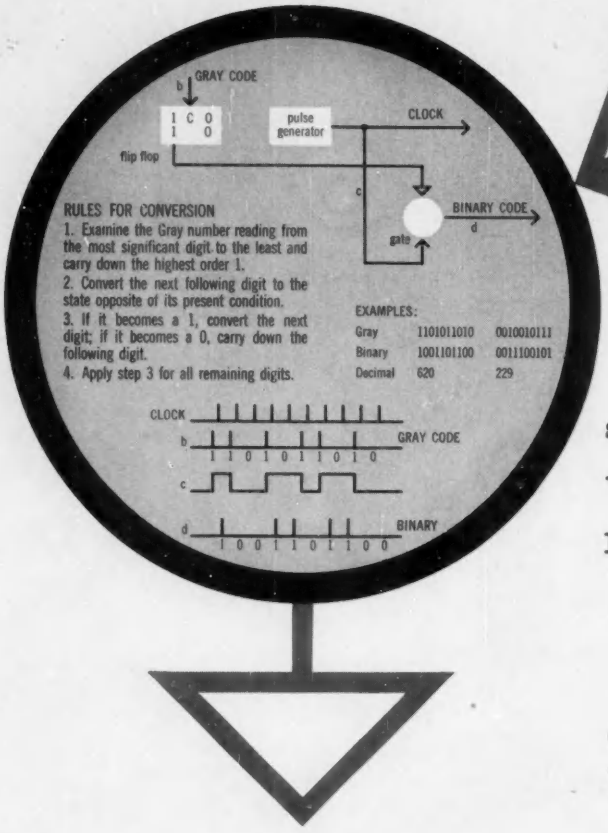
†For higher currents, G-E High Current Rectifiers may be used, or Stacks may be used in parallel.



AXIAL LEAD MOUNTED. See the versatility of G-E Axial Lead models. They're easy to mount anywhere you need low current silicon rectifiers.

Progress Is Our Most Important Product

GENERAL ELECTRIC



solving logical problems with Burroughs pulse control systems

converting Gray code to binary equivalents

Here is a simple method for converting Gray code to true binary equivalents. It was put into operation in minutes just by interconnecting Burroughs Pulse Control Units in accordance with the engineer's block diagram, without detailed specifications or complicated circuit designs. With pulse control equipment at his disposal, the engineer was able to turn immediately to other important problems awaiting his attention.

The majority of engineers solving logical problems are badly in need of such tools. Most are bogged down by equipment of limited use that must be redesigned and rebuilt for every new project . . . that clutters the path to a working solution instead of clearing and shortening it.

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Control ENGINEERING
APRIL 1957

Worry NOW About Dynamics

Each month on this page we keynote an event or subject of major significance to you. We offer you our analysis, convictions, and advice. This month we ask you to recognize an upsurge of technical society activity in standardization of dynamic tests and statements. We advise you to study the progress of the technical society groups involved and to contribute your help. It's in your selfish interest to do it.

The Instrument Society of America, the American Institute of Electrical Engineers, and the Institute of Radio Engineers have subcommittees at work on establishing ways of measuring and describing dynamic response. ISA Recommended Practices Subcommittee RP 26 is in the lead with a draft recommended practice ready for review and approval. (See page 37 of this issue for a full report on the subcommittee's accomplishments and aims.) AIEE's Feedback Control Systems Subcommittee is close behind with a 19-man group of specialists instructed to "add to and consolidate existing specifications to indicate the dynamic and other characteristics which the system designer needs." (See Feb. '57 *Feedback*, page 10, for the subcommittee roster and a description of its objectives.) IRE's Feedback Control technical subcommittee on standards for measuring and describing the performance of feedback control systems has scheduled a report for six months from now. Curiously, the subcommittee is numbered 26.1, the same number assigned to the draft of the ISA recommended practice. Surely the magic of numbers will strengthen the common professional endeavor linking the two.

You'll eventually use or furnish the dynamic response data. To make certain that it is consistent with your needs, better contact:

ISA: F. H. Winterkamp, Sabine River Works, E. I. du Pont de Nemours & Co., Inc., Orange, Tex.

AIEE: H. Chestnut, General Electric Co., One River Rd., Schenectady, N. Y.

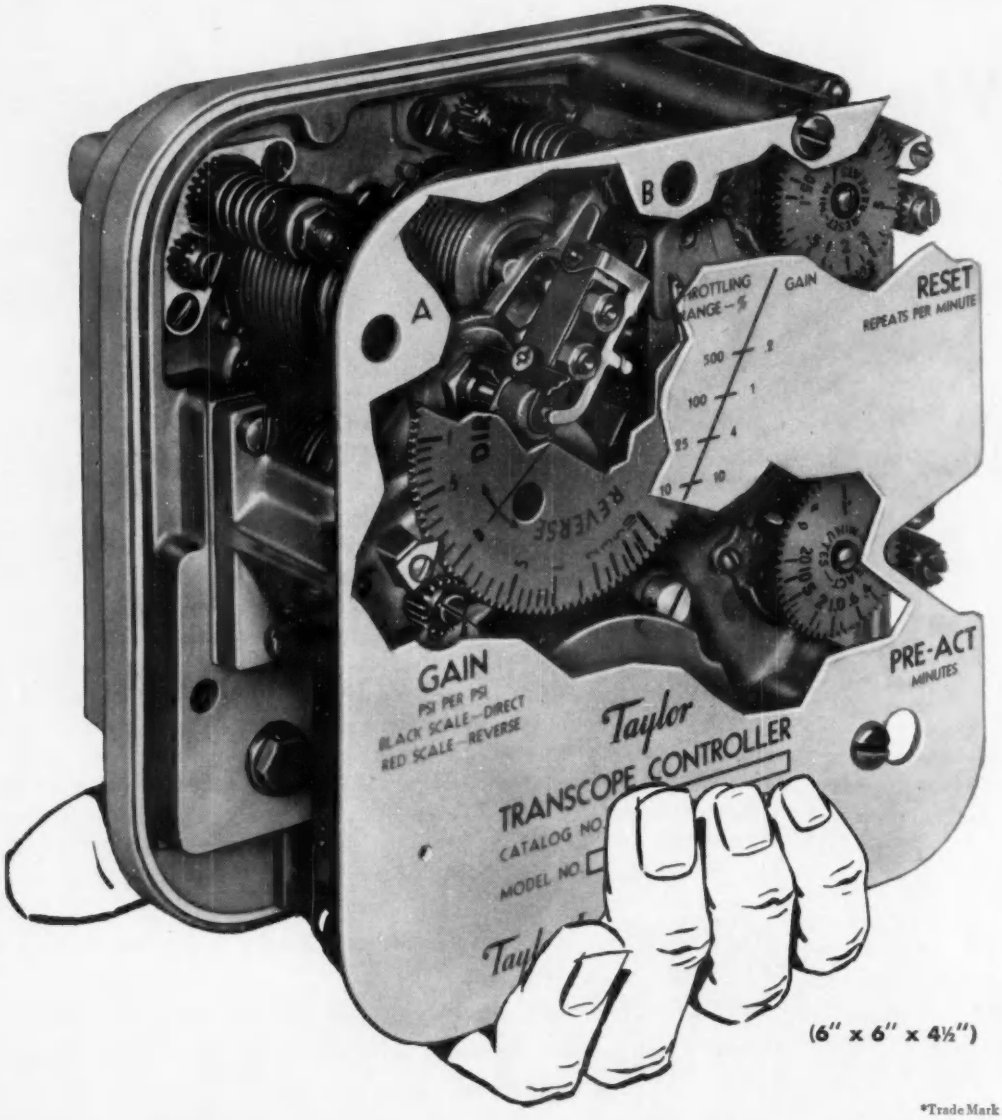
IRE: John E. Ward, Servomechanisms Laboratory, MIT, Cambridge, Mass.

What's in it for you if you devote time, thought, and company knowledge to these subcommittees? It's this: serious worrying now about dynamics will save you some painful headaches after the standard practices are laid down.

THE EDITORS

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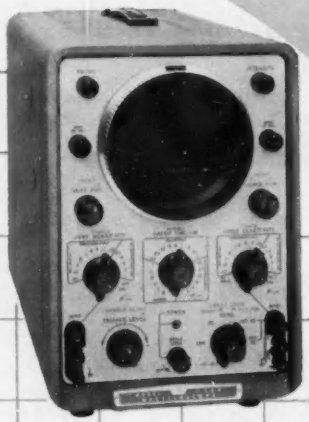
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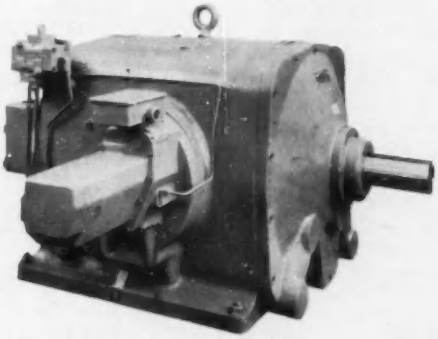


FIG. 1. Two-way variable-delivery pump with electrohydraulic servo control. Pumps of this type have been applied to large extrusion presses, forming presses, and other special presses.

NORBERT J. NITKA, The Oilgear Co.

THE GIST: The controllability and speed of response of both rotary and linear hydraulic drives make them ideal for many systems requiring automatic position or speed control. Above approximately 5 hp, hydraulic systems using variable-displacement pumps seem particularly well-suited for high-power industrial applications due to their efficiency, simplicity, and reliability. The key to the use of these pumps in high-performance closed-loop systems is the electrohydraulic stroker, which varies pump delivery rate in proportion to a low-level electrical input signal. Applications of these systems range across the field of industrial machinery: forming presses, extrusion presses, flying shears, grinders, etc.

If load characteristics are known, straightforward linear-servo analytical techniques can replace trial and error approaches, assuring specified performance. The following material includes a special section describing the basic stroker-pump package, and an analysis of typical position and speed-control systems, showing how to design the basic package into these systems. This procedure is followed in designing a position-control system for a hardboard press; test results show the validity of the analytical procedure.

Except for low-power aircraft applications, closed-loop control systems using variable-displacement hydraulic pumps have not been widely used. Those systems that were designed for the most part had mechanical or hydraulic feedback between the controlled machine and the hydraulic pump stroker. Where electrical signal circuitry was used, the system was usually of the "on-off" type with a large electrical stroke motor. The design approach consisted of arranging a feasible system on paper, making sure that it contained sufficient variable components to permit adjustment for stable operation during the initial stages of operation.

With the perfection of the electrohydraulic stroker and the increased use of the operational approach to closed-loop system analysis, the closed-loop hydraulic-pump control system has become a versatile and well-arranged package with predictable response. Using as the basic block a pump with electrohydraulic stroker, the system designer often can simply select the right hydraulic ram or motor, and the proper electrical transducers to measure the output and convey the information to the electrical amplifier. Figure 1 shows a typical pump-and-stroker combination. The electrical half of the stroker is a low-voltage, low-power unit; the high force gain is obtained from hydraulic amplifiers built into the pump. When an accurate description of the load is available, a standard linear servo analysis will predict quite accurately the allowable gain for stability, system accuracy, and the speed of response.

The special section on the following three pages points out the performance characteristics and capabilities of the basic block of pump and stroker and describes this packaged portion of a control system starting at the variable-displacement pump and working through to the signal input circuitry. The transfer function of the electrical stroker is derived for use in the analysis of position and speed closed-loop control systems, which continues on page 85.

THE ELECTROHYDRAULIC SERVO—Basic System Component

An electrohydraulic control system using a variable-displacement hydraulic pump in a closed loop includes the controlled system (or load), a rotary or linear hydraulic actuator, feedback transducers, and input elements (or a programmer), in addition to the electrical and hydraulic amplifying and pumping devices. In specifying and applying this equipment, the amplifying and pumping subsystem can often be considered as a package that will deliver hydraulic fluid at a volumetric rate proportional to an input voltage signal. Knowing the characteristics of available "packages", the proper one, together with the other required equipment, can be incorporated in systems for controlling position, speed, load, synchronization, etc. The following describes, and outlines the performance characteristics of the electrical and hydraulic amplifying and pumping equipment that make up a typical servo package.

The pump

Figure I shows a variable-displacement hydraulic pump. The radial pumping pistons are contained in bores in the cylinder, which is driven by a constant-speed electric motor. The pistons are retained by the thrust ring held in the slide block. The pumping cylinder bores are connected to outlet ports through the stationary pintle valve. If the thrust ring and cylinder are concentric, the pistons do not move with respect to their bores and no pumping takes place. But if the slide block is moved, making the thrust ring eccentric with respect to the cylinder, the pistons move out on one side and in on the opposite side, drawing oil from one port and delivering it to the other. Since the slide block can be moved to either side of the cylinder center line, the unit can pump in either direction.

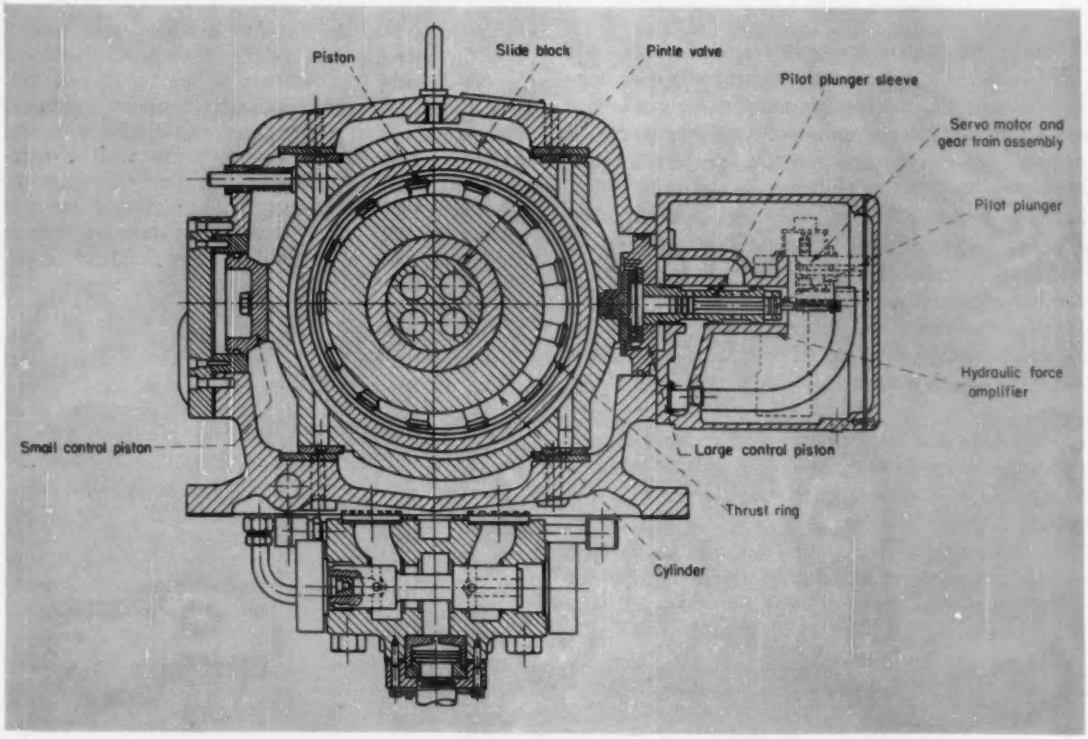
The hydraulic stroke cylinders

To vary pump delivery, the slide block must be moved and held, requiring a rather large force. On a 150-hp unit, the maximum force is about 8,000 lb at maximum eccentricity and pump pressure. Stroking cylinders built into the pump case are used to produce this large restraining force on the slide block. A bias cylinder of sufficient area to overcome the control reaction force when supplied by 150-psi pilot pressure is used on one side of the slide block. A cylinder of approximately twice the area on the opposite side is supplied from control valving. A stroke of 1.062 in. is required on the 150-hp unit to give full reversible flow.

Hydraulic force amplifiers

A valve and cylinder hydraulic amplifier, Figure I, provides most of the force amplification, while the electrical components operate at a low power level. Hydraulic amplifiers are simple, high-gain, high-accuracy devices. Since the valve bushing is mechanically connected to the stroker cylinder, the cylinder must move the same distance as the valve plunger. With 150-psi supply pressure, a maximum output force of 3,000 lb is obtained with an input force on the valve plunger of a fraction of a pound. Posi-

FIG. 1. Cutaway of variable-displacement hydraulic pump and electrohydraulic stroker.



tioning accuracy depends on the change in valve position required to supply valve and cylinder leakage under extremes in loading. Under typical conditions, a change in valve opening of less than 0.001 in. takes care of slip variations.

The closed-loop electrical stroker

The electrical stroker positions the hydraulic amplifier valve plunger in accordance with the magnitude of an electrical input signal. For industrial applications, the equipment must be reliable and simple and able to operate on 110 volts, 60 cps throughout. Figure II shows a schematic, and Figure III the block diagram.

The signal voltage from a command potentiometer is compared with the output voltage of a feedback potentiometer, connected by gearing to the electrical stroke motor. The error signal voltage, amplified in the magnetic amplifier, drives the stroke motor until feedback potentiometer output equals command potentiometer voltage. The electrical stroker motor is coupled to the valve plunger through precision gearing. Tachometer feedback is used for stabilization.

Since the closed-loop electrical stroker is independent of the hydraulic stroke system (except for valve plunger load on electrical motor), the overall stroking accuracy can be no better than the accuracy of the electrical stroker. The latter has a small dead band since a small error voltage is required to produce sufficient torque at the stroke motor to overcome the friction of the valve plunger and the friction in the electrical stroker itself. The friction torque of the hydraulic valve is below 0.5 in.-lb at the electrical stroker output shaft, and the friction in the electrical system is considerably less than this. With this friction load, and with the hydraulic stroker adding an error of 0.0005 in., the overall slide-block position error is less than 1 percent of full stroke.

The electrical stroker should give life comparable to normal expected pump life. The weak points in the system are the rectifiers and the feedback potentiometer. But even metallic-type rectifiers should last about as long as the pump, and tests run on wire-wound potentiometers show lives of over 10 million wipes when oscillated at 2 to 3 cps over an amplitude of 180 deg either in oil or air.

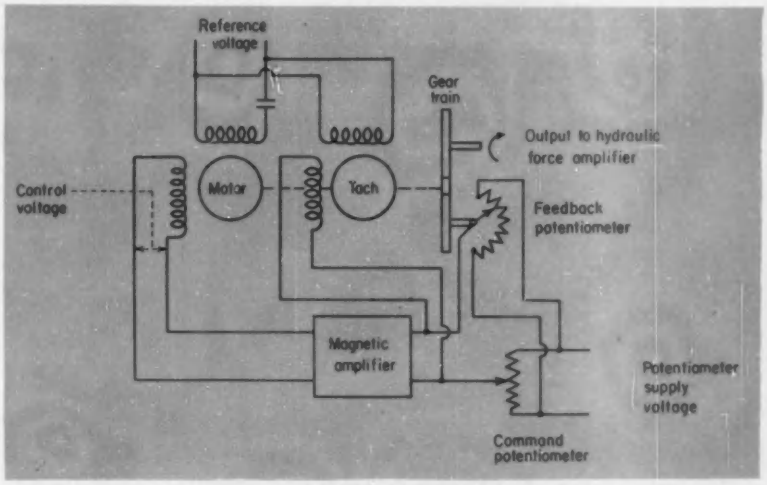


FIG. II. Schematic of electrical stroker.

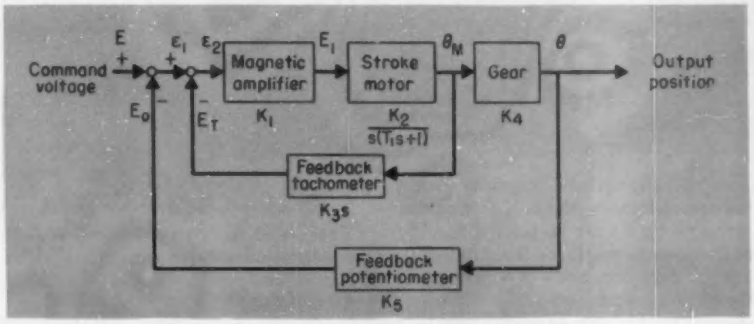


FIG. III. Block diagram of electrical stroker.

Analysis of the electrical stroker

Figure IV shows the bridge-type magnetic amplifier. Response time is independent of gain, depending only on supply frequency. Output voltage is produced only when the bridge circuit is unbalanced. With zero signal input, the reset circuits bring both cores to the same point on their identical magnetization curves. This occurs during the half-cycle when the load circuit is blocked by the rectifiers and is nonconducting. When an input signal is applied, the signal current in the in-series-opposing input coils tends to further magnetize one core and demagnetize the other. Thus, during this half-cycle, the magnetic amplifier cores store information as to the magnitude of the input signal. During the load-conducting half-cycle, one side of the bridge is driven to saturation before the other, the time interval between saturation of the cores being proportional to the magnitude of the input signal. During this time interval, the bridge is unbalanced and current flows through the load. Power is supplied to the load in the form of pulses, at a frequency equal to the supply frequency and of a magnitude proportional to the signal..

The exact transfer function of the magnetic amplifier is quite nonlinear, since the output voltage is a series of pulses that are parts of a sine wave, and the period between pulses is a constant equal to the reciprocal of the supply frequency. However, since the pulse frequency is high compared to system response, the output voltage can be taken as the average value of the pulses and the delay time can be ignored. The amplifier transfer function is then a constant, K_1.

The two-phase ac stroke motor has an approximate transfer function $K_2/s(T_1s + 1)$. The drag-cup tachometer transfer function is K_3s. The gear train and feedback potentiometer have constants for transfer functions, K_4 and K_5, respectively.

Solving for the inner-loop transfer function of Figure III gives

$$G_1(s) = \frac{K_1K_2}{s(T_1s+1)} \; ; \; H_1(s) = K_3s$$

Therefore

$$M_1(s) = \frac{1}{\dfrac{s(T_1s+1)}{K_1K_2} + K_3s}$$

$$= \frac{K_1K_2}{s(T_1s+1+K_1K_2K_3)}$$

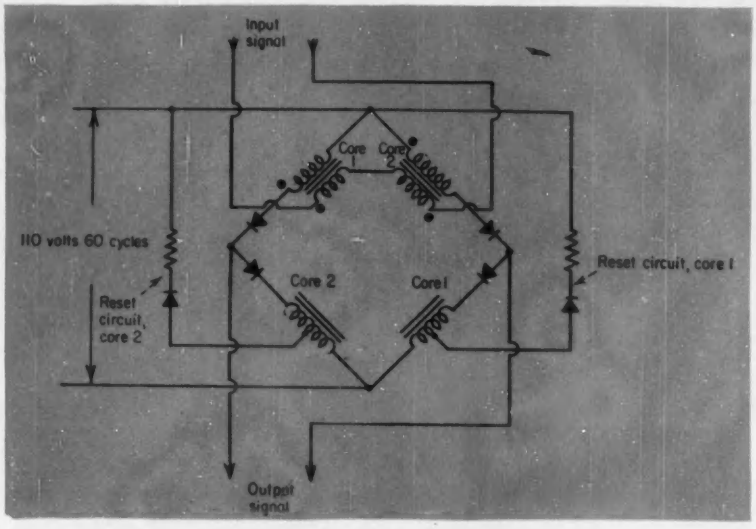


FIG. IV. Bridge-type magnetic amplifier.

The overall transfer function giving the closed-loop response of the system can now be found by solving for the potentiometer feedback loop and combining the resultant function with the previous equation:

$$G(s) = \frac{K_1K_2K_4}{s(T_1s+1+K_1K_2K_3)} \quad ; \quad H(s) = K_5$$

$$M(s) = \frac{1}{\frac{s(T_1s+1+K_1K_2K_3)}{K_1K_2K_4} + K_5}$$

$$= \frac{K_1K_2K_4}{T_1s^2+(1+K_1K_2K_3)\,s+K_1K_2K_4K_5} \quad \text{(I)}$$

This, in turn, can be written in nondimensional form:

$$M(s) = \frac{\theta(s)}{E(s)} = \frac{K_T}{\frac{s^2}{\omega_E^2} + \frac{2\zeta_E}{\omega_E}s+1} \quad \text{(II)}$$

where

θ = output angular position
E = input command signal voltage
K_T = system gain $= 1/K_5$

ω_E = natural frequency $= \sqrt{\dfrac{K_1K_2K_4K_5}{T_1}}$

ζ_E = damping coefficient

$$= \frac{1+K_1K_2K_3}{2\sqrt{K_1K_2K_4K_5T_1}}$$

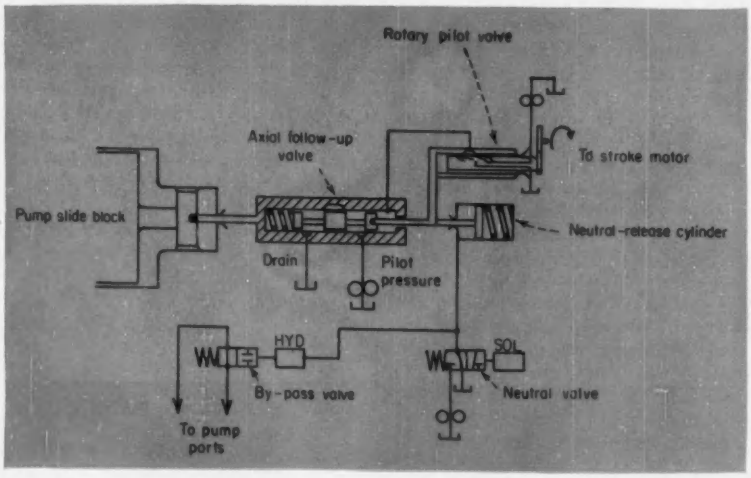
To have sufficient feedback potentiometer movement, the 4-to-20-hp units use a 5-to-1 reduction to the feedback potentiometer and an additional 8-to-1 reduction to the output shaft. With optimum gain this system has an ω_E of 56 rad/sec, and a ζ_E of 0.2. The 35-to-150-hp units use a 40-to-1 reduction to the output shaft, with the feedback potentiometer coupled to the output shaft. With optimum gain ω_E is 20 rad/sec, and ζ_E is 0.5.

Signal circuitry

The stroke feedback potentiometer is a 5,000-ohm unit connected across the 110-volt, 60-cps line. The simplest command circuit is therefore a 5,000-ohm potentiometer connected across the line. However, this must be modified if the same electrical stroking system is to be used with various pumps having different length strokes.

The unit can also be programmed by using telephone-type relays to switch in various potentiometers and to provide a signal for pump neutral when all channels are de-energized. Thus, different volumetric pump outputs can be selected either manually from a selector switch, or automatically from limit switches on the controlled equipment.

FIG. V. Safety features of hydraulic stroker. Notice that this stroker uses a two-stage hydraulic force amplifier, the first stage being a rotary screw-type valve rather than a linear valve. This type of a valve is ideal for driving with a rotary actuator.



Auxiliary safety equipment

In the event of power or oil-supply failure, the equipment should automatically switch to its safest stopping condition. As shown in Figure V, the pump control includes a three-way solenoid valve that ports oil to the first hydraulic stage and to the neutral release cylinder only while the valve solenoid is energized. If power to the solenoid fails, or pilot pressure is lost, the pump returns to neutral. In addition, a by-pass valve is usually connected across the pump ports and held closed by hydraulic pressure from this same three-way valve. Whenever the pump is neutralized it is also bypassed to prevent creeping if the pump does not return to exact neutral. The smaller units do not have stroke neutralizing but rely completely on a solenoid-operated by-pass valve to stop output motion.

Position-control systems

Figure 2 shows a typical input signal circuit for an electrohydraulic position-control system. A position-command/position-feedback potentiometer bridge is placed in series with the stroke-command/stroke-feedback bridge normally used to command the stroker. If a hydraulic ram (or hydraulic motor) is to be positioned, the pump stroke command is set to balance the stroke-feedback potentiometer when the position error is zero. The output position of the system then follows the position-command potentiometer. If one ram or hydraulic motor is to follow another, both moving at constant velocity, both stroke commands are set for the desired velocity. Any difference in position as measured by a position-error feedback potentiometer calls for a readjustment of velocities to eliminate the error between the moving power units.

The first analysis deals with a closed-loop position-control system in which desired output position is set on the position-command potentiometer and the hydraulic ram or motor moves to this position and stops. As derived in the special section, the electrical-stroker transfer function is

$$\frac{\theta(s)}{\epsilon(s)} = \frac{K_T}{\frac{s^2}{\omega_E^2} + \frac{2\zeta_E}{\omega_E}s + 1}$$

Since the natural frequency of the hydraulic stroke valves is much greater than that of the electrical stroker, the frequency dependent factors in the valve transfer function can be neglected. The hydraulic stroking system then has a single time constant due to the motion of the stroke piston, and negligible inertia. Thus the hydraulic stroker transfer function is

$$\frac{X(s)}{\theta(s)} = \frac{K_H}{\frac{s}{T_H} + 1} \qquad (1)$$

where $T_H \cong \frac{K_V}{A_S}$

K_V = final-stage valve gain (flow per unit motion)
A_S = stroke cylinder area

Pump flow can be assumed directly proportional to slide-block displacement, and the effect of leakage and oil compressibility lumped with the load.

$$\frac{Q(s)}{X(s)} = K_P \qquad (2)$$

Neglecting the piping pressure drops (appreciable in only a few extreme cases), the motor-load transfer function for a linear motor (ram) is

$$\frac{X_O(s)}{Q(s)} = \frac{1/A}{s\left(\frac{CM}{A^2}s^2 + \frac{M}{A^2R_P}s + 1\right)} \qquad (3)$$

where A is the ram area, M the total mass of the ram and load, C the "capacitance" or compressibility factor of the system, and R_P the leakage rate of pump and cylinder. Similarly, the rotary hydraulic motor has a motor-load transfer function

$$\frac{X_O(s)}{Q(s)} = \frac{1/d_m}{s\left(\frac{CJ}{d_m^2}s^2 + \frac{J}{d_m^2R_P}s + 1\right)} \qquad (4)$$

where d_m is the motor displacement, and J the total moment of inertia of motor and load. A nondimensional transfer function, describing the linear and rotary motor, can also be written:

$$\frac{X_O(s)}{Q(s)} = \frac{K_O}{s\left(\frac{s^2}{\omega_L^2} + \frac{2\zeta_L}{\omega_L}s + 1\right)} \qquad (5)$$

where for the linear motor

$$K_O = 1/A$$
$$\omega_L = A/\sqrt{CM}$$
$$\zeta_L = (1/2AR_P)\sqrt{M/C}$$

and for the rotary motor

$$K_O = 1/d_m$$
$$\omega_L = d_m/\sqrt{CJ}$$
$$\zeta_L = (1/2d_mR_P)\sqrt{J/C}$$

Since the feedback potentiometer produces a voltage proportional to output position, its transfer function is

$$\frac{E_O(s)}{X_O(s)} = K_F \qquad (6)$$

Multiplying all the transfer functions gives the open-loop transfer for the system:

$$G(s)H(s) = \frac{E_O(s)}{\epsilon(s)} = \frac{K_EK_HK_PK_OK_F}{s\left(\frac{s}{T_H}+1\right)\left(\frac{s^2}{\omega_E^2}+\frac{2\zeta_E}{\omega_E}s+1\right)\left(\frac{s^2}{\omega_L^2}+\frac{2\zeta_L}{\omega_L}s+1\right)} \qquad (7)$$

Figure 4 shows a frequency-response plot for a

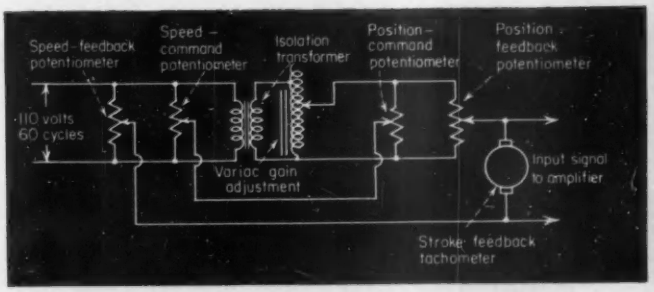


FIG. 2. Signal circuit for closed-loop position control.

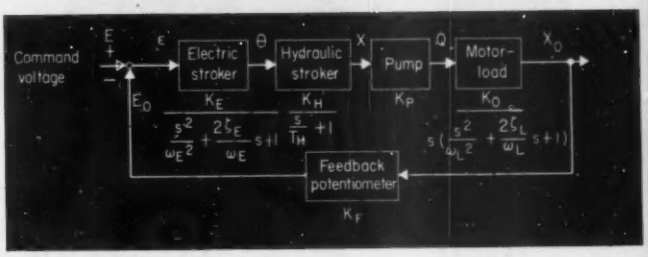


FIG. 3. Block diagram of closed-loop position-control system.

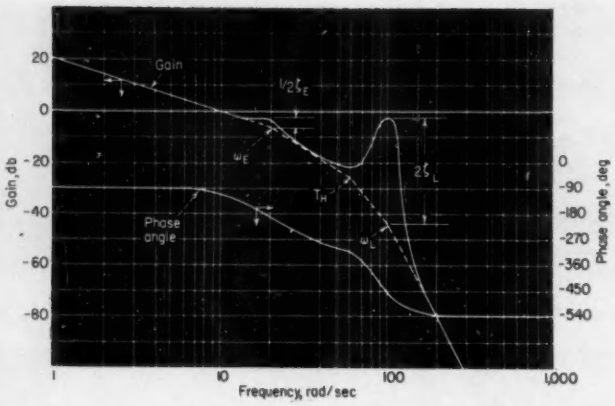


FIG. 4. Open-loop frequency-response curves for typical closed-loop position control of a ram.

typical system. All of the system gains are usually fixed, except for the feedback potentiometer gain, K_F, which can be adjusted for an optimum system. This adjustment can be made by varying the voltage across the potentiometer or by changing the mechanical ratio between the output and the potentiometer. For ram loads, ω_L is usually very high, but ζ_L is very low and gain can be adjusted to bring the peak at ω_L to zero db. The gain can actually be increased to bring the resonant peak 10 to 20 db above the zero-db line, since most rams have considerable friction damping that cannot easily be accounted for mathematically. For rotary motor loads, usually $\omega_L < \omega_E$ and the gain is adjusted for proper gain margin at ω_L.

The system steady-state error depends on the change in motor and pump slip with change in load. To hold the load in a given position, the stroker must supply any slip flow demanded by the operating pressure required to support the load. The small slip flow means that the pump must be slightly on stroke, which in turn means a small voltage output from the electrical stroker and a small position error between command and output. This position error can be calculated as follows:

$$\Delta E_O = \epsilon(t)\Big|_{\text{state}}^{\text{steady-}}$$

$$= \lim_{s \to 0} s\left(\frac{Q_l}{s}\right)\left[\frac{\left(-\frac{s^2}{\omega_E^2} + \frac{2\zeta_E}{\omega_E}s + 1\right)\left(\frac{s}{T_H} + 1\right)}{K_E K_H K_P}\right]$$

$$= \frac{Q_l}{K_E K_H K_P} \qquad (8)$$

This gives the voltage the feedback potentiometer must produce. The actual position error is

$$\Delta X_O = \Delta E_O / K_F \qquad (9)$$

Since for stable operation the system must cross the zero-db line on the 20-db/decade slope of the 1/s term, the system time constant can be approximated as follows:

$$G(s) \cong \frac{K_E K_H K_P K_O}{s} \quad ; \quad H(s) = K_F$$

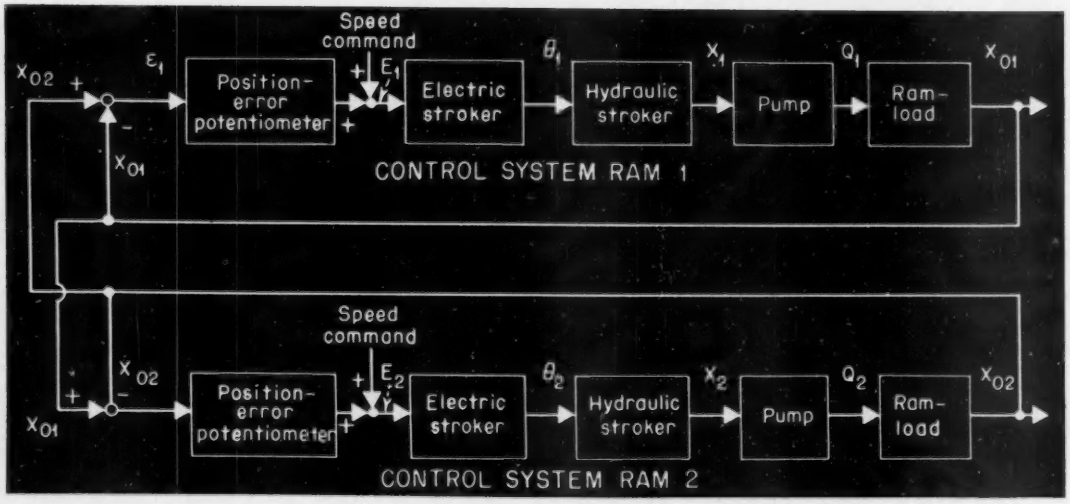
$$M(s) \cong \frac{K_E K_H K_P K_O}{s + K_E K_H K_P K_O K_F}$$

and the time constant, T, is

$$T \cong K_E K_H K_P K_O K_F \qquad (10)$$

Figure 5 shows a system with two rams or rotary motors following at constant velocity with small position error. It differs from the position-follower system above only in that a mechanical error is derived before converting to an electrical signal, allowing the rams to move over a long stroke while

FIG. 5. Press-brake type of closed-loop position-control system. Two rams are synchronized to travel at same speed with zero position error.



measuring only their difference in position, and the analysis is identical to that for the position follower. On press brakes errors in beam level can be held below a few thousandths of an inch on a 1,000-ton machine. Surprisingly, larger press-brake systems show promise of even higher accuracies since they operate at low speeds, allowing more gain in the error-measuring system.

Speed-control systems

Figure 6 shows a typical error-signal circuit and Figure 7 the system block diagram for a closed-loop speed-control system in which the output speed as measured by a tachometer follows the speed-command voltage set on a command potentiometer. The inner position loop of the electrical stroker is left out to obtain an integration from the stroker. With the inner loop closed the system is unstable.

The electrical stroker with only tachometer feedback has the transfer function

$$\frac{\theta(s)}{\epsilon(s)} = \frac{K_1K_2K_4}{s\,(T_1s + 1 + K_1K_2K_3)} \tag{11}$$

which can be written

$$\frac{\theta(s)}{\epsilon(s)} = \frac{K_E}{s(s/T_E + 1)} \tag{12}$$

where

$$K_E = K_1K_2K_4/(1 + K_1K_2K_3)$$
$$T_E = (1 + K_1K_2K_3)/T_1$$

The hydraulic-stroker and pump transfer functions are identical to those of the position-control system as given by Equations 1 and 2. The motor-load transfer function loses the 1/s term since output is now velocity instead of position:

$$\frac{V_O(s)}{Q(s)} = \frac{K_O}{\frac{s^2}{\omega_L{}^2} + \frac{2\zeta_L}{\omega_L^2}\,s + 1} \tag{13}$$

And the feedback tach has the transfer function

$$\frac{E_O(s)}{V_O(s)} = K_T \tag{14}$$

Multiplying the transfer functions gives the open-loop response:

$$G(s)H(s) = \frac{E_O(s)}{\epsilon(s)} = \frac{K_EK_HK_PK_OK_T}{s\left(\frac{s}{T_H}+1\right)\left(\frac{s}{T_E}+1\right)\left(\frac{s^2}{\omega_L{}^2}+\frac{2\zeta_L}{\omega_L}s+1\right)} \tag{15}$$

Figure 8 shows typical frequency-response curves. The zero-db crossover point for a stable system is at the initial 20-db/decade slope due to the 1/s term. For a rotary motor the load quadratic is usually the lowest frequency element and gain is adjusted for the proper margin at ω_L, giving optimum response at the load. For a ram motor, ω_L is usually high, and the response is determined by T_H or T_E. The high resonant peak at ω_L for the low-damped ram system must be inspected for proper gain margin at this frequency, and gain may have to be sacrificed to prevent high-frequency oscillation.

Because of the integrating action of a velocity servo, the steady-state velocity error is zero if the system is linear for small changes in output speed. This is shown by the following:

$$\epsilon(t)\Big|_{\substack{\text{steady-}\\\text{state}}} = \lim_{s\to 0} s\left(\frac{V_O}{s}\right) \times \left[\frac{s\left(\frac{s}{T_H}+1\right)\left(\frac{s}{T_E}+1\right)\left(\frac{s^2}{\omega_L{}^2}+\frac{2\zeta_L}{\omega_L}s+1\right)}{K_EK_HK_PK_OK_T}\right]$$

$$\epsilon(t)\Big|_{\substack{\text{steady-}\\\text{state}}} = 0$$

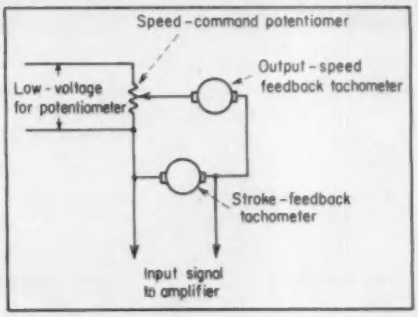


FIG. 6. Signal circuit for closed-loop speed control.

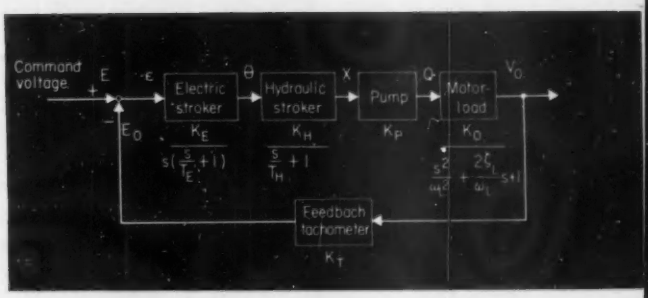


FIG. 7. Block diagram of closed-loop speed-control system.

However, the first hydraulic valve plunger requires a small motor torque to break its friction. Until motor torque increases above the amount necessary to break this friction, the stroke motor cannot move and the integration does not appear. Therefore, to calculate speed error,

$$\epsilon(t)\Big|_{\substack{\text{steady-}\\\text{state}}} = \lim_{s\to 0} s\left(\frac{\Delta E}{s}\right) \times \left[\frac{\left(\frac{s}{T_H}+1\right)\left(\frac{s}{T_E}+1\right)\left(\frac{s^2}{\omega_L{}^2}+\frac{2\zeta_L}{\omega_L}+1\right)}{K_EK_HK_PK_OK_T}\right] = \frac{\Delta E}{K_EK_HK_PK_OK_T} \tag{16}$$

where ΔE is the error voltage necessary to produce sufficient stroke motor torque to break the valve

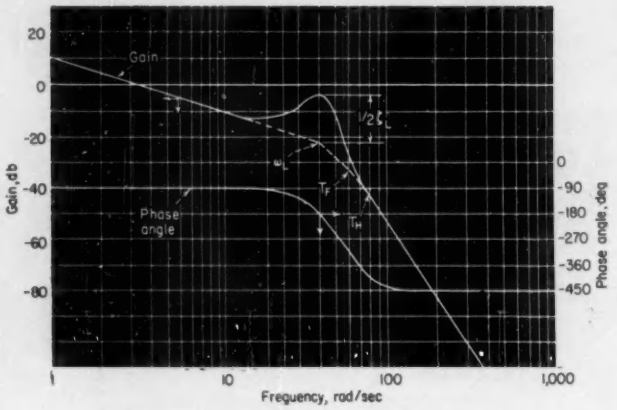


FIG. 8. Open-loop frequency-response curves for typical closed-loop speed control of a hydraulic motor.

friction. Note that the error is a constant independent of speed, and therefore speed error may be a large percentage of operating speed at low operating speeds.

Since the system-response curve crosses the zero-db line at a slope of 20 db/decade, the system time constant can be approximated as follows:

$$G(s) \cong \frac{K_E K_H K_P K_O K_T}{s} \quad ; \quad H(s) = K_T$$

$$M(s) \cong \frac{K_E K_H K_P K_O}{s + K_E K_H K_P K_O K_T}$$

And the time constant, T, is

$$T \cong K_E K_H K_P K_O K_T \tag{17}$$

In terms of system response time to a step input, it takes a time $t = 1/T$ for a 63-percent correction, and a time $t = 4/T$ for a 98-percent correction.

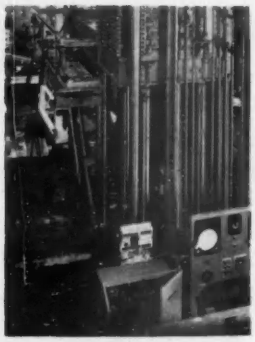
DESIGNING A TYPICAL SYSTEM

THE PROBLEM—Figure 9 shows two views of a 750-ton hardboard press. Hardboard is manufactured in a conventional press by using only a pressure-curing cycle. The numerous plates are loaded equally with the hardboard material and then heated and compressed. When the material has reached approximately the desired thickness, pressure is alternately relieved and reapplied a number of times. The final dimension is not controlled directly, but only indirectly by controlling pressures during the curing. This system departs from the conventional circuit by adding a final position-control system to hold the overall dimension for the total thickness of all the boards within a closer tolerance. Since the loading of the material onto each plate can be held quite accurately, it follows that the thickness of the individual boards can also be held to closer tolerances.

The design problem is to obtain a stable system with reasonable speed of response that will produce a final position of the 623-sq-in., 100-in.-stroke cylinders within $\frac{1}{32}$-in. total deviation. The available power unit is a 108-gpm, 2,500-psi hydraulic pump, selected to give the proper open-loop speeds to the press.

AND THE SOLUTION—Figure 10 shows the oil and control circuit for the close-loop position-control system. The variable-delivery hydraulic pump meters oil into or from the working cylinders. The amount of oil transferred to or from the cylinders is determined by the electrohydraulic pump stroker, which is commanded, through the magnetic amplifier, by the electrical position-error signal. Ram position is measured by a rectilinear potentiometer. The command circuitry to the amplifier is the same as shown in Figure 2, and Figure 3 represents the system block diagram.

The component transfer functions are computed on the next page.



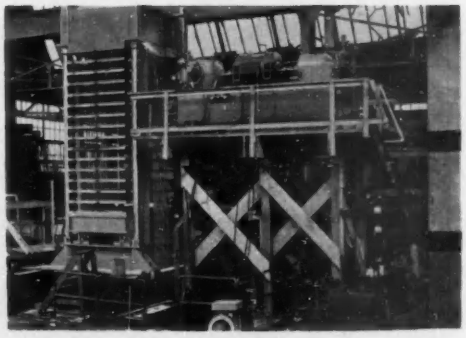


FIG. 9. Two views of hardboard press manufactured by Washington Iron Works of Seattle, Wash. Note hydraulic pump and control unit similar to that shown in Figure 1.

Electrical stroker

K_1 = amplifier gain = 12 volts/volt
K_2 = motor speed per volt = 4.5 rad/sec/volt
K_3 = tach voltage per unit speed = 0.007 volts/rad/sec
K_4 = gear ratio = 0.025 rad/rad
K_5 = pot voltage per unit angular motion = 19 volts/rad
T_1 = motor time constant = 0.066 sec
$K_E = 1/K_5 = 0.0526$

$$\omega_E = \sqrt{\frac{K_1K_2K_4K_5}{T_1}} = 20 \text{ rad/sec}$$

$$\zeta_E = \frac{1 + K_1K_2K_3}{2\sqrt{K_1K_2K_4K_5T_1}} = 0.53$$

$$\frac{\theta(s)}{\epsilon(s)} = \frac{K_E}{\frac{s^2}{\omega_E^2} + \frac{2\zeta_E}{\omega_E}s + 1} = \frac{0.0526}{\frac{s^2}{20^2} + \frac{1.06}{20}s + 1}$$

Hydraulic stroker

K_H = linear output motion per unit rotary input motion = 0.051 ft/rad
K_V = valve flow per unit motion = 35 ft³/sec/ft
A_S = stroke cylinder area = 0.75 ft²

$$T_H = K_V/A_S = 47 \text{ sec}^{-1}$$

$$\frac{X(s)}{\theta(s)} = \frac{0.051}{(s/47) + 1}$$

Pump

$$\frac{Q(s)}{X(s)} = K_P = 5.45 \text{ ft}^3/\text{sec/ft}$$

Ram and load

A = total area of rams = 4.3 ft²
M = total platen mass = 3,100 slugs
C = compressibility factor = βv
β = compressibility coefficient = 4×10^{-6} in.²/lb for oil used
v = total volume of system = 70,000 in.³
C = (4×10^{-6}) (70,000) in.⁵/lb = 1.1×10^{-6} ft⁵/lb
R_P = leakage rate of pump and cylinder = $\Delta P/Q_L$

$$R_P = \frac{1{,}000 \text{ lb/in.}^2}{1{,}000 \text{ in.}^3/\text{min}} = 1.5 \times 10^7 \text{ lb-sec/ft}^5$$

$$K_O = 1/A = 0.23 \text{ ft}^{-2}$$

$$\omega_L = A/\sqrt{CM} = 74 \text{ rad/sec}$$

$$\zeta_L = (1/2AR_P)\sqrt{M/C} = 4 \times 10^{-4}$$

$$\frac{X_O(s)}{Q(s)} = \frac{0.23}{s\left(\frac{s^2}{74^2} + \frac{8 \times 10^{-4}}{74}s + 1\right)}$$

Feedback potentiometer

$$\frac{E_O(s)}{X_O(s)} = K_F$$

Choose K_F for proper system response.

Overall system

Multiplying the component transfer functions together gives the open-loop transfer function for the entire system. This is equivalent to substituting in Equation 7.

$$\frac{E_O(s)}{\epsilon(s)} = \frac{3.4\,K_F \times 10^{-3}}{s\left(\frac{s^2}{20^2} + \frac{1.06}{20}s + 1\right)\left(\frac{s}{47} + 1\right)\left(\frac{s^2}{74^2} + \frac{8 \times 10^{-4}}{74}s + 1\right)}$$

The frequency response curve, Figure 11, shows that 62 db more gain can be allowed if the resonant peak (at $\omega_L = 74$ rad/sec) is moved to + 10 db (this assumes unaccounted-for damping will drop the peak 10 db). Then K_F is 10^3 ft/volt or 83 volt/in. In the actual system, a 0-110-volt Variac was used to supply a 1-in. potentiometer.

The steady-state position error can be computed as follows:

$$\Delta E_O = \frac{Q_L}{K_E K_H K_P} = \frac{0.18(0.24)}{0.053(0.051)\ (5.45)} = 2.94 \text{ volts}$$

$$\Delta X_O = \frac{\Delta E_O}{K_F} = \frac{2.94}{110} = 0.027 \text{ in.}$$

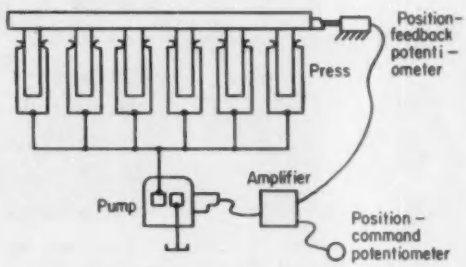


FIG. 10. Schematic of hardboard-press position-control system.

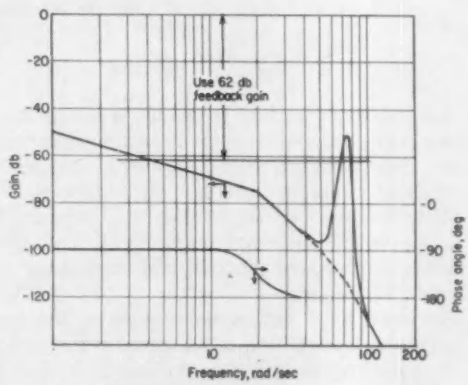


FIG. 11. Open-loop frequency response of hardboard-press with position control.

Thus, the maximum position error is 0.027 in., within the specified tolerance of $\frac{1}{32}$ in. The approximate time constant can be calculated as follows:

$$T = K_E K_H K_P K_O K_F = 4 \text{ sec}^{-1}$$

Therefore the response time for a 98-percent correction is about 1 sec.

This hardboard machine was recently tested and will soon go into production. Field-test reports state that with the Variac gain set at maximum ($K_F = 110$ volts/in.) the system was stable and responded rapidly. A dial indicator showed that final platen position was held within 0.030 in.

USE DIFFERENCE EQUATIONS to Calculate Frequency Response from Transient Response

The problem of converting the transient response of a system and its input into the system's frequency response alone occurs frequently in the design, analysis, and synthesis of servos and other closed-loop control systems. Hal Levenstein's numerical technique (Prony's method[2]) uses linear difference equations to develop an exact and straightforward approach. It serves as an alternate to approximating numerical Fourier methods and can be adapted to machine computation.

H. LEVENSTEIN, The W. L. Maxson Corp.

Relations in a linear dynamic system are most conveniently manipulated on a frequency-response, or operational basis, where the work is primarily an algebraic problem. However, it frequently happens that after the system designer has reduced the descriptions of his components to this form, the data available represent the transient response of the system. Theoretically, since the system relations are described by a differential equation, the transient response representing a solution of the differential equation contains all the necessary data. Rephrasing this as frequency-response information usually means an approximation to the Fourier or Laplace integral transformations, and subsequent curve-fitting if the analytical expression is required. A good technique is the graphical one proposed by Teasdale[1], in which the transient response is converted to frequency response by adding vectors.

The difference equation representing the transient response can also be used to infer the frequency response. This method is theoretically exact, systematic, lends itself to machine computation, and yields an analytical solution. The assumptions associated with using difference equations for converting from transient to frequency response are no more restrictive than those required by other methods: the system, constructed of linear elements, is describable by a linear differential equation with constant coefficients, and the input, or command, function has a rational Laplace transform. Thus, the commonly-used step-change input, 1/s, for example, satisfies the latter assumption.

The justification for the difference equation method is that it can uniquely represent the solution of a linear differential equation. This uniqueness will be proven, and once done the differential equation no longer enters into this method.

The difference equation method proceeds in an orderly manner:

1. Take data at equal time intervals from the transient record.
2. Assume, from a knowledge of the physical system, the order of the difference equation.
3. Solve for the coefficients of the difference equations. Coefficients correspond to residues at the poles of the transfer function to be found.
4. Find the roots of the difference equation. Roots correspond to the modes of the transfer function to be found.
5. Define the time solution using known roots and coefficients.
6. Write the solution in partial fraction form.
7. Divide the partial fraction by the Laplace transform of the input function.

This yields the transfer function of the system under consideration.

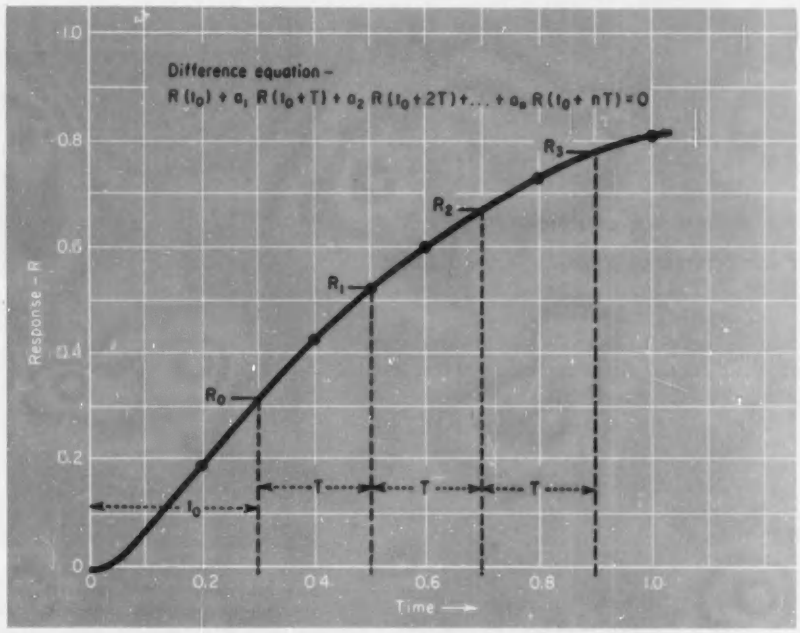


FIG. 1. In the difference equation method of converting from transient to frequency response the transient response is divided into equal time intervals, T, and the numerical value of the response is noted at each sampling point. The numerical values subsequently yield the transfer function of the system and of the input function. By dividing out the transfer function of the input, the transfer function of the system itself is obtained. Note here that the first sample occurs at t_o to show the general case. In the example solved in the text the first sample occurs at t equal to zero, so that t_o equals zero.

Solving the difference equation

As a start, assume that the time response of a linear system, Figure 1, can be represented by a linear difference equation of the form:

$$R(t_0)+a_1R(t_0+T)+a_2R(t_0+2T)+\ldots+a_nR(t_0+nT)=0 \quad (1)$$

Thus, the sum of $(n+1)$ suitably-weighted responses, each separated by an interval T, adds up to zero. The length of the interval nT, or equivalently the number $(n+1)$ of terms required, depends on the complexity of the differential equations describing the system and the input.

Assume Equation 1 has a solution in the form:

$$R(t_0+kT)=cr^{t_0+kT} \quad (2)$$

Substituting Equation 2 into Equation 1, term by term, yields:

first term	$R(t_0) = cr^{t_0}$
second term	$a_1R(t_0+T) = a_1cr^{t_0+T}$
third term	$a_2R(t_0+2T) = a_2cr^{t_0+2T}$
nth term	$a_nR(t_0+nT) = a_ncr^{t_0+nT}$

Collecting like terms results in an algebraic equation in powers of r^T:

$$cr^{t_0}(1+a_1r^T+a_2r^{2T}+\ldots+a_nr^{nT})=0 \quad (3)$$

The characteristic equation, the bracketed expression set equal to zero, will be satisfied whenever r^T is a root of the equation. There will be n roots, r_1 to r_n, and each will represent a nontrivial solution. cr^{t_o} may be disregarded because it contributes a trivial solution.

Thus, the solution of the difference equation can be written:

$$R(t_0+kT)=c_1r_1^{(t_0+kT)}+c_2r_2^{(t_0+kT)}+c_3r_3^{(t_0+kT)}+\ldots+c_nr_n^{(t_0+kT)} \quad (4)$$

Here, the c's are independent of time and determined by initial conditions.

NOMENCLATURE

$C(t)$	command-function of time
$C(s)$	Laplace transform of $c(t)$
$R(t)$	response-function of time
$R(s)$	Laplace transform of $R(t)$
r_i	roots of difference equation
a_i	coefficients of difference equation
p	d/dt
s	complex variable in Laplace transform
s_i	roots, or modes, of differential equation
c_i	coefficients in solution of difference equation
b_i	coefficients in solution of differential equation
T	sampling interval
n	order of the difference equations
k	ordering number for samples
t	time
t_o	time at R_o

Solving the differential equation

Suppose the differential equation of the transient response to be:

$$L(p)\,R(t) = M(p)\,C(t)$$

where L and M are polynominals and p represents differentiation. Assume all derivatives are zero initially. Taking Laplace transforms results in

$$R(s) = \frac{M(s)}{L(s)}\,C(s) = \frac{M(s)}{L(s)} \cdot \frac{N(s)}{D(s)}$$

where $C(s) = N(s)/D(s)$. Finding the roots of $L(s)\,D(s)$ leads to the evaluation of the time response. The time solution[3] for simple roots is:

$$R(t) = \sum_{i=1}^{n} \frac{M(s_i)\,N(s_i)}{\frac{d}{ds}[L(s)\,D(s)]} \exp(s_i t) \qquad (5)$$

$$= b_1 \exp(s_1 t) + b_2 \exp(s_2 t) + \ldots + b_n \exp(s_n t) \qquad (6)$$

Let $r_i = \exp s_i$
then $r_i^t = \exp s_i t$
and $r(t_o + kT) = \exp s_i t_o + s_i kT)$

Since Equation 6 is true for all values of time it can be written in the same form as Equation 4:

$$R(t_0 + kT) = b_1 \exp(s_1 t_0 + s_1 kT) + b_2 \exp(s_2 t_0 + s_2 kT) + \ldots$$
$$= b_1 r_1^{(t_o + kT)} + b_2 r_2^{(t_o + kT)} + \ldots + b_n r_n^{(t_o + kT)} \qquad (7)$$

Thus the roots of the difference equation and the differential equation are simply and uniquely related. Likewise, because the expansion of a function in a finite sum of exponentials is a unique expansion, the b's are also identical to the c's.

Finding difference equation from transient response

The difference equation of the response is fairly simple to find. As an example, consider a second-order lag system excited by a step-change (single-order lag) input. The difference equation will then be third-order:

$$R_0(t_0) + a_1 R(t_0 + T) + a_2 R_2(t_0 + 2T) + a_3 R_3(t_0 + 3T) = 0$$

The three unknown coefficients require three sets of data from the transient response, taken at times kT where k ranges from 0 to 5. Numbering the data in sequence, three simultaneous equations result:

$$\begin{aligned} a_1 R_1 + a_2 R_2 + a_3 R_3 &= -R_0 \\ a_1 R_2 + a_2 R_3 + a_3 R_4 &= -R_1 \\ a_1 R_3 + a_2 R_4 + a_3 R_5 &= -R_2 \end{aligned} \qquad (8)$$

The solution for the three coefficients in Equations 8 in determinant form is:

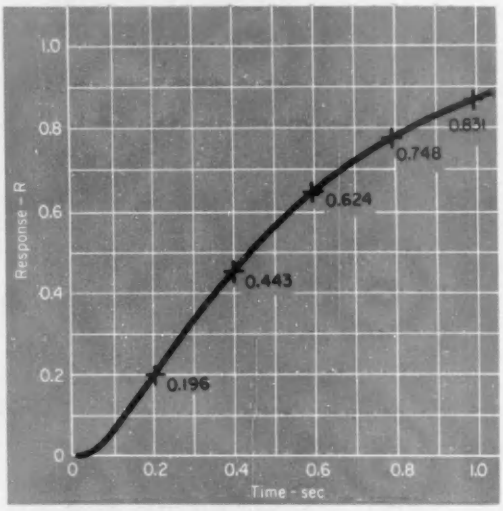


FIG. 2. This curve represents the transient response of a second-order system subjected to a step-change input, resulting in a third-order transient response. The numerical data determined in equal time intervals on this curve and used in the difference equation method supplies the transfer function of the system. Thus, the difference equation method easily converts this transient response to its equivalent frequency response.

$$a_1 = -\frac{\begin{vmatrix} R_0 & R_2 & R_3 \\ R_1 & R_3 & R_4 \\ R_2 & R_4 & R_5 \end{vmatrix}}{\begin{vmatrix} R_1 & R_2 & R_3 \\ R_2 & R_3 & R_4 \\ R_3 & R_4 & R_5 \end{vmatrix}} \qquad (9A)$$

$$a_2 = -\frac{\begin{vmatrix} R_1 & R_0 & R_3 \\ R_2 & R_1 & R_4 \\ R_3 & R_2 & R_5 \end{vmatrix}}{\begin{vmatrix} R_1 & R_2 & R_3 \\ R_2 & R_3 & R_4 \\ R_3 & R_4 & R_5 \end{vmatrix}} \qquad (9B)$$

$$a_3 = -\frac{\begin{vmatrix} R_1 & R_2 & R_0 \\ R_2 & R_3 & R_1 \\ R_3 & R_4 & R_2 \end{vmatrix}}{\begin{vmatrix} R_1 & R_2 & R_3 \\ R_2 & R_3 & R_4 \\ R_3 & R_4 & R_5 \end{vmatrix}} \qquad (9C)$$

The determinants are easily solved by Crout's method[2].

The values a_1, a_2, and a_3 are substituted into the algebraic equation, Equation 3, defining the roots of the difference equation:

$$1 + a_1 x + a_2 x^2 + a_3 x^3 = 0 \qquad (10)$$

where $x = r^T$. If the roots of this equation are x_i the corresponding residues of the differential equation are:

$$s_i = \frac{1}{T} \log x_i \qquad (11)$$

To find the residues at the poles, s_i, substitute the x_i and the corresponding values of R_i into the solu-

tion of the difference equation, Equation 4. For this third-order system the equations becomes:

$$\begin{aligned} R_0 &= c_1 + c_2 + c_3 \\ R_1 &= c_1 x_1 + c_2 x_2 + c_3 x_3 \\ R_2 &= c_1 x_1^2 + c_2 x_2^2 + c_3 x_3^2 \end{aligned} \tag{12}$$

This is readily solved for the c's, using determinants. The Laplace transform of the system is then:

$$R(s) = \frac{c_1}{s - s_1} + \frac{c_2}{s - s_2} + \frac{c_3}{s - s_3} \tag{13}$$

and the transfer function of the system itself, after dividing by the Laplace transform of the input function, 1/s, is:

$$\frac{R(s)}{C(s)} = \frac{c_1 s}{s - s_1} + \frac{c_2 s}{s - s_2} + \frac{c_3 s}{s - s_3} \tag{14}$$

From Equation 14 the frequency-response plots or other data can be calculated by conventional means.

An example of difference equation method

Teasdale[1] illustrated his method by a two-section *RC* network excited by a step input, thus giving rise to a third-order response, Figure 2. The same response will be used to illustrate the conversion from transient to frequency response by the difference-equation method.

The data obtained from the record at equal intervals of time are:

t sec	R
0	0
0.2	0.196
0.4	0.443
0.6	0.624
0.8	0.748
1.0	0.831

Solve the following simultaneous equations for the coefficients of the characteristic equation defining the third-order difference equation:

$$\begin{aligned} 0.196\, a_1 + 0.443\, a_2 + 0.624\, a_3 &= 0 \\ 0.443\, a_1 + 0.624\, a_2 + 0.748\, a_3 &= -0.196 \\ 0.624\, a_1 + 0.748\, a_2 + 0.831\, a_3 &= -0.443 \end{aligned} \tag{15}$$

The characteristic algebraic equation is:

$$13\, x^3 - 23\, x^2 + 11x - 1 = 0$$

and the roots are:

$$\begin{aligned} x_1 &= 1 \\ x_2 &= 0.654 \\ x_3 &= 0.118 \end{aligned}$$

The corresponding residues at the poles are:

$$\begin{aligned} s_1 &= 0 \\ s_2 &= -2.12 \\ s_3 &= -10.7 \end{aligned}$$

The response, at 0.2 sec intervals, can be written, since $t_0 = 0$, from Equation 4:

$$R(kT) = c_1(1)^k + c_2(0.654)^k + c_3(0.118)^k$$

At large values of k, $R(kT)$ approaches unity; c_1, therefore, is unity. At $k = 0$ and 1, $R(kT)$ becomes:

$$\begin{aligned} 1 + c_2 + c_3 &= 0 \qquad k = 0 \\ 1 + 0.645\, c_2 + 0.118\, c_3 &= 0.196 \qquad k = 1 \end{aligned}$$

Therefore

$$\begin{aligned} c_2 &= -1.28 \\ c_3 &= 0.28 \end{aligned}$$

Thus, from Equation 13:

$$R(s) = \frac{1}{s + 0} - \frac{1.28}{s + 2.12} + \frac{0.28}{s + 10.7}$$

and, dividing by the Laplace transform of the input function, 1/s:

$$\frac{R(s)}{C(s)} = 1 - \frac{1.28s}{s + 2.12} + \frac{0.28s}{s + 10.7} \tag{16}$$

yields the desired transfer function, and hence the frequency response.

The exact transfer function of the network model used by Teasdale is:

$$\frac{R(s)}{C(s)} = 1 - \frac{1.25s}{s + 2.0} - \frac{0.25s}{s + 10.0}$$

and the above compares favorably to this.

The calculated time response can be found without recourse to Equation 16 or a table of inverse Laplace transforms. Since the b's and c's of Equations 6 and 4 are identical, Equation 6 yields the time response in terms of the b_i's and s_i's previously determined. Hence:

$$\begin{aligned} R(t) &= c_1 \exp(s_1 t) + c_2 \exp(s_2 t) + c_3 \exp(s_3 t) \\ &= c_1 e^{s_1 t} + c_2 e^{s_2 t} + c_3 e^{s_3 t} \\ &= 1e^{0t} - 1.28e^{-2.12t} + 0.28e^{-10.7t} \\ &= 1 - 1.28e^{-2.12t} + 0.28e^{-10.7t} \end{aligned}$$

A note of caution: considerable care must be taken with the numerical work, otherwise some odd answers arise. It is good practice to check the derived roots of the difference equation by calculating the response at points not used for their derivation. The necessity for assuming the order of the difference equation is not ordinarily a confining one since the physical structure of the device or system under test usually suggests the proper order.

REFERENCES

1. *GET FREQUENCY RESPONSE FROM TRANSIENT RESPONSE BY ADDING VECTORS.* A. R. Teasdale, "Control Engineering", October 1955.

2. *INTRODUCTION TO NUMERICAL ANALYSIS.* F. B. Hildebrand, McGraw-Hill Book Co., Inc., New York, 1955.

3. *TRANSIENTS IN LINEAR SYSTEMS.* M. F. Gardner and J. L. Barnes, John Wiley & Sons, Inc., New York, 1942, Chapter VI, p. 152.

Dynamic Stability Control Increases Aircraft Range

For static stability in flight, an aircraft's lift center of pressure must lie aft of its center of gravity. But equal and opposite forces at these points produce a couple, thus demanding a certain amount of elevator trim. With dynamic stability, however, where the center of gravity and lift center of pressure may be coincident, the need for elevator trim is obviated, drag is reduced, and "lift/drag" ratio is increased.

The most important advantage of such a system is the increase in maximum range—range being proportional to the L/D ratio. Other advantages of dynamic stability include less shift in the center of pressure and better performance in gusts normal to the flight path. In designing the necessary control system, the nonlinear effects of "downwash" and "upwash" should be considered, along with inner-loop stability, safety, and reliability.



FIG. 1. Airframe with statically derived stability.

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In conventional airframe design, stability and control characteristics are based upon a well-known axiom: for a body to remain stable while passing through a fluid, the center of pressure of the lateral force, resulting from an incremental change in angle of attack, must always lie aft of the center of gravity. In other words, the slope of the pitching moment versus the lift-coefficient curve should be negative; e.g., a nose-down pitching moment should accompany a nose-up increase in the pitch angle of attack.

The feathered arrow is one application of this stability principle and was undoubtedly discovered by empiricism; another is in a piloted aircraft, which would attempt to invert itself and fly backwards if this principle were not designed into it.

Although the aircraft should be able to maintain its own stability, there are special cases, such as during a shift in payload or an error in the manual scheduling of fuel distribution between tanks, where a little negative static stability can be tolerated for brief periods. When this occurs in large aircraft, where rate of divergence is relatively slow, the pilot can usually respond in time to provide the necessary stabilizing control. The effect produced here will be termed "dynamic stability", and later will be compared to "static stability".

Stability is seen to stem from appropriate control-surface action as well as from the relative location of the center of gravity and lift center of pressure. This introduces the question: can the static stability of an airframe be supplanted by dynamic stability, and, if so, what are the advantages of such an arrangement? It will be shown that this can be done by using automatic closed-loop control and that the result is improved range, speed, and operational suitability.

Some Basic Comparisons

The weathervane stabilizing moment

Figure 1 shows an airframe angularly displaced in the pitch plane from a trim condition. Note that the restoring moment is derived, in whole or in part, from the angle of attack of the horizontal tail surfaces—as the instantaneous angle of attack increases, the restoring moment increases. This indicates that stability is simply a matter of applying the right force to the airframe at the right place and time.

In Figure 2, the airframe again is angularly disturbed from a trim condition but in this case it has been made neutrally stable by arranging the CG and CP coincident to each other. No restoring moment is obtained by the change in lift coefficient; instead, the elevator is dynamically deflected so that its angle of attack is proportional to the instantaneous angle of attack of the wing-body combination. In effect, the stabilizing moment has been dynamically increased without actually increasing the tail area; or, so far as stability is concerned the CP has effectively, but not actually, moved aft of the CG.

This method is not to be confused with the familiar damper type of stability augmenter, where elevator deflection angle is made proportional to the derivative of the airframe angle of attack; with dynamic stability, the weathervane natural frequency is affected rather than the damping.

Analytic comparison

To determine stability and control characteristics of an aircraft equipped with an automatic maneuver-control system requires a complete closed-loop analysis. That is, the control system and its contribution to the aircraft's stability characteristics must be included with the airframe's static characteristics. The degree to which the dynamic (controlled) characteristics differ from the static (locked controls) characteristics depends on how the airframe and control system designs have been blended. Figure 3, which illustrates this, is a block diagram of the pitch system

DEFINITIONS

- a_Z Linear acceleration along Z axis, ft/sec².
- Z_w Pitch linear acceleration coefficient due to pitch angle of attack, ft/sec²/ft/sec.
- Z_δ Pitch linear acceleration coefficient due to elevator deflection angle, ft/sec²/rad.
- M_w Pitch moment coefficient due to pitch angle of attack, rad/sec²/ft/sec.
- M_q Pitch moment coefficient due to pitch rate, rad/sec²/rad/sec.
- M_δ Pitch moment coefficient due to elevator deflection angle, rad/sec²/rad.
- U Linear velocity along X axis, ft/sec.
- K_1 Elevator angular velocity/pitch linear acceleration coefficient, rad/sec/ft/sec².
- K_2 Elevator angular velocity/pitch angular rate coefficient, rad/sec/rad/sec.
- K_3 Elevator angular velocity/pitch angular acceleration coefficient, rad/sec/rad/sec².
- δ_E Elevator deflection angle, rad.
- $\dot{\delta}_E$ Elevator deflection rate, rad/sec.
- S Laplace operator.

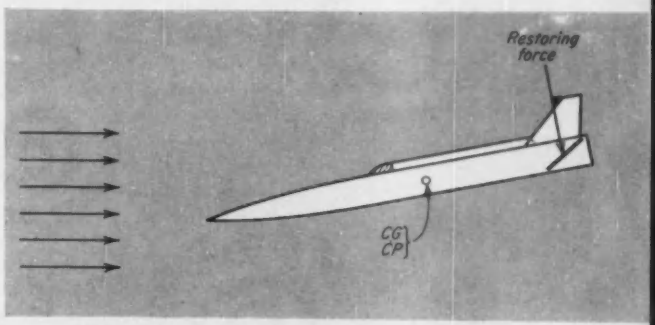
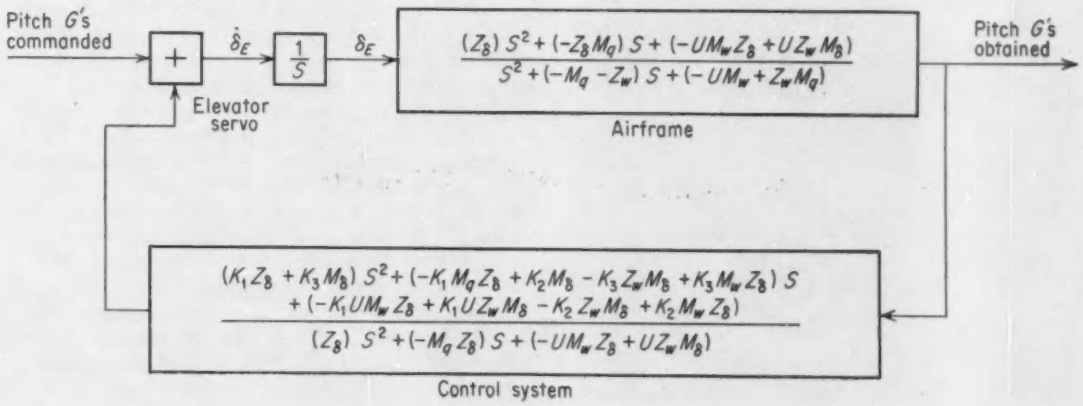


FIG. 2. Airframe with dynamically derived stability.

FIG. 3. Block diagram of an automatic pitch system



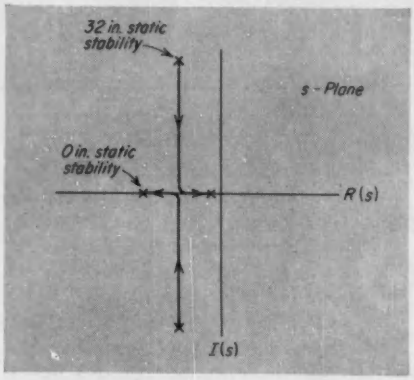


FIG. 4. Locus of roots vs. static stability.

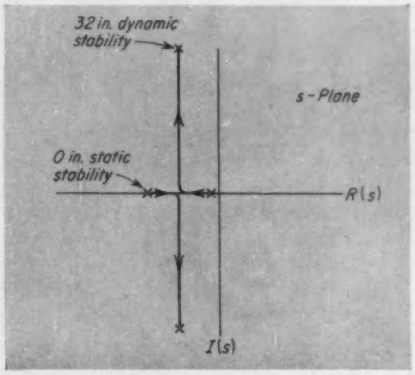


FIG. 5. Locus of roots vs. dynamic stability.

in an aircraft capable of high maneuver performance. The automatic maneuver-control system is simply a linear-acceleration-type controller employing angular rate and angular acceleration feedback in conjunction with a velocity-type servo. The feedback signals, which sense the airframe motions, are analytically described by the transfer function of the lower block. The automatic control loop is closed when these signals are fed into a fast-response, hydraulically actuated mechanism which, in turn, actuates the control surface.

The stability and control characteristics of the airframe alone may be determined by extracting the poles and zeros of the airframe block, while those of the airplane as a whole may be determined by adding the zeros of the control system to the poles of the airframe block and elevator servo block. The characteristic equation which must be used to make valid conclusions about stability and control is:

$$G(s)\,H(s)+1=S^3+(-M_q-Z_w+K_1Z_\delta+K_2M_\delta)S^2 +(-U\,M_w+Z_wM_q-K_1M_qZ_\delta+K_2M_\delta-K_2Z_wM_\delta +K_2M_wZ_\delta)S+(-K_1U\,M_wZ_\delta+K_1U\,Z_wM_\delta -K_2Z_wM_\delta+K_2M_wZ_\delta)=0$$

By plotting the roots of a typical airframe equation on a complex s-plane, in Figure 4, the natural angular frequency, damped angular frequency, and damping ratio of the airframe weathervane characteristic can be determined. Initially, this airframe was not equipped with an automatic control system; it was stabilized by the static method of having the CG forward of the CP, a distance of 32 in. As the CG is moved aft toward the CP, the arrows denote the locus of roots of the equation for the uncontrolled airframe. End points of the locus denote CG and CP coincidence. The airframe may be considered neutrally stable at this point. It has lost its oscillatory weathervane characteristic and its transfer function is described by two cascaded time constants. If the CG is moved further aft, the longer time constant becomes a slow nonoscillatory divergence; that is, the airframe will slowly attempt to invert itself and fly backwards.

Using the locus of the roots, Figure 5 shows how the control system dynamically supplies the restoring moment usually supplied by locating the CG forward of the CP. If only that portion (the K_2 term) of the control system that moves the elevator is activated, the instantaneous elevator angle of attack becomes proportional to the instantaneous airframe angle of attack. Then, as the gain in this channel of the automatic control system is increased, the roots return to their original position, i.e. the 32-in. static stability point of Figure 4. (Note: the characteristic equation actually becomes a cubic but because the effect of the new root is trivial it is not included in Figure 5).

Steady-state relations

There are several advantages associated with a neutrally stable airframe. Figures 6A, 6B, and 6C show a sample airframe in a 3-g pitch-up maneuver with plus 32 in., 0 in., and minus 32 in. of static stability, respectively. Steady-state relations for these figures were determined from the following relations:

$$\left.\frac{\text{Pitch g's}}{\text{Degrees elevator deflection}}\right|_{\text{Steady-state}} = \begin{bmatrix}1\\1847\end{bmatrix}\begin{bmatrix}-UM_wZ_\delta+UZ_wM_\delta\\-UM_w+Z_wM_q\end{bmatrix}$$

$$\left.\frac{\text{Degrees pitch angle of attack}}{\text{Pitch g's}}\right|_{\text{Steady-state}} = \frac{1847}{U^2}\begin{bmatrix}UM_\delta-Z_\delta M_q\\Z_wM_\delta-M_wZ_\delta\end{bmatrix}$$

As static stability moves from positive to negative, (Figures 6A to 6C): (1) there is a reduction in angle of attack, the result of using the horizontal tail as an efficient lifting surface, (2) the neutrally stable airframe requires zero elevator deflection at any angle of attack (ignoring CP shifts with angle of attack, for the moment) thus permitting pitch maneuver magnitudes that are not restricted by a given elevator effectiveness, and (3) there is a limitation that must be placed on the forward location of the CP (with respect to the CG) to prevent the elevators' stabilizing effect from being locked out by the deflection limit. In Figure 6C the clockwise moment created by the 32 in. of negative static stability requires 12 deg of positive elevator deflection to zero the steady-state sum of the pitching moments. In this example, pitch maneuver is 3 g's,

and the CP can be as far as 40 in. forward of the CG before the elevator deflection limit (plus or minus 15 deg) is reached. With appropriate automatic control, the steady-state moment equation determines how far forward of the CG the CP can be located. Contrast this to manual control, wherein the CP can never be forward of the CG.

Advantages of Dynamic Stability

Better L/D ratio

An important parameter in the range equation for aircraft is the lift/drag, or "L/D ratio". For maximum range, this ratio must be at maximum value. This means that the more lift obtained, coincident with the drag penalty required to get it, the greater will be the airplane's range. To find the relation between the parasite drag, C_{D_o}, and the induced drag, C_{D_i}, pursuant to a maximum L/D ratio, consider a well-known theorem in aerodynamics:

$$C_D = C_{D_o} + C_{D_i}$$

Since induced drag, C_{D_i}, is proportional to the square of the lift coefficient, C_L, it follows that,

$$C_D = C_{D_o} + \frac{C_{D_i}}{C_L^2} C_L^2$$

or, dividing both sides by C_L,

$$\frac{C_D}{C_L} = \frac{C_{D_o}}{C_L} + \frac{C_{D_i}}{C_L^2} C_L$$

Setting the derivative equal to zero,

$$d\left[\frac{C_D}{C_L}\right] = -\frac{C_{D_o}}{C_L^2} + \frac{C_{D_i}}{C_L^2} = 0$$

Hence the maximum L/D ratio occurs when induced drag equals parasite drag. This can be represented in graphical form by referring to a drag polar, Figure 7. Note that the tangent of the maximum L/D ratio always occurs when induced drag equals parasite drag.

Since any trim drag will degrade the L/D ratio, its maximum will occur when the center of lift is located at the same point on the longitudinal body axis as the center of gravity; that is, when the uncontrolled airframe is neutrally stable.

For example, refer back to Figures 6A and 6B. Considering only first-order effects, when the 32 in. of static stability is replaced with 32 in. of equivalent dynamic stability, the angle of attack is reduced by 20 percent because the elevator now provides positive rather than negative lift. Based on the square-law relation, this means that induced drag for this airplane has been reduced 36 percent by making the airframe neutrally stable. In terms of range performance, maximum range has been increased 22 percent by means of an automatic control system.

There will be large variations in the performance improvements that can be realized in other aircraft by application of this stability principle. In subsonic aircraft, for instance, trim drag is quit low to begin with. On the other hand, the airstream flow conditions peculiar to most supersonic airframes are such that the lift center of pressure moves aft a considerable distance as speed becomes supersonic. Thus static stability increases, and this causes an increase in trim drag. Here the usefulness of the stability principle becomes quite appreciable because the airframe can be designed with neutral stability at its cruise Mach number, even though it is statically unstable in subsonic operation—an arrangement not possible in nonautomatically controlled airplanes.

It may seem at first that the advantages of a neutrally stable airframe are limited to the tail-controlled airplane because a negative lift is associated with the control moment in this configuration. However, a study of a drag polar for the canard, or "tail first" type, would show that a neutrally stable airframe is necessary here, too, to maximize the lift/drag ratio, although the canard is not nearly as critical in this respect since the forward control surface always gives positive lift forces.

Less affected by CP and CG shifts

When the airframe configuration is such that the CP shifts with angle of attack, the control system has to be designed so that the amount of dynamic stability varies as a nonlinear function of the angle of attack. Unfortunately, this cannot be done with

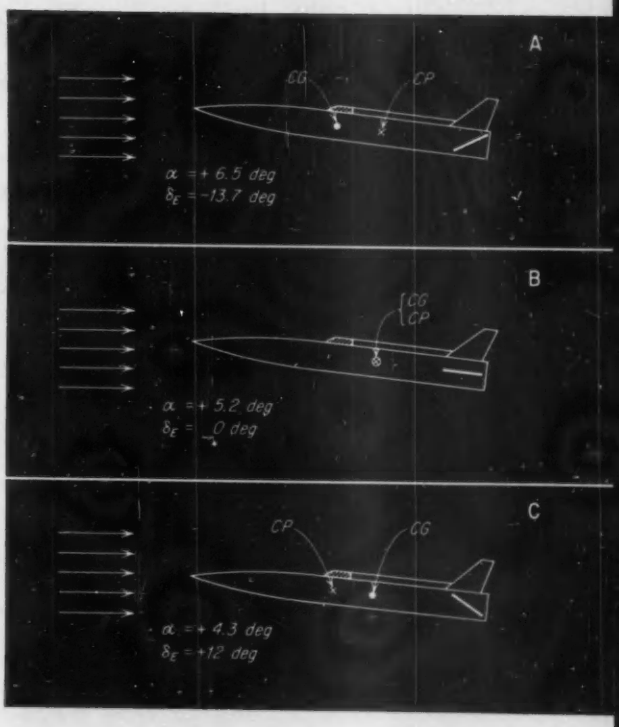


FIG. 6. Typical airframe with A) plus 32 in. of static stability; B) 0 in. of static stability; C) minus 32 in. of static stability.

simple autopilot circuitry because of the nonlinear multiplication involved.

A definite advantage, however, is the fact that a neutrally stable airframe extends the pitch-g operation envelope for which the CP does not shift, because the angle of attack required for a given pitch maneuver is reduced.

Although shifts in longitudinal CG affect stability and control analogous to CP shifts the automatic control system permits shifting the CG aft until it is coincident with the CP, thus allowing the elevator to trim out at such a position that the lift/drag ratio of the horizontal tail is optimum.

No angular acceleration in gusts

As already shown, a dynamically stable aircraft has stability and control characteristics essentially identical to those of a statically stable aircraft, with one difference worth noting: gusts normal to the flight path impart linear acceleration but no angular acceleration to the dynamically stable airframe. When the airframe is used as an aerial gun (or bombing) platform, the advantage of neutral stability becomes even more evident: no angular acceleration is imparted to the airframe by a rough air environment. Contrast this to the more conventional method of platform stabilization, where angular oscillations are damped rather than eliminated at the source.

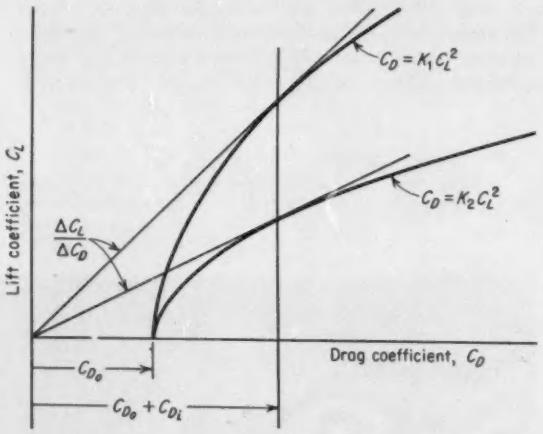


FIG. 7. Drag polar illustrating points of maximum L/D ratio.

Note also that the neutrally stable airframe behavior in gusts depends on the number of aerodynamic loops closed. That is, if only the loop providing dynamic stability is closed, the aircraft will not intrinsically attempt to reduce the angle-of-attack change represented by the gust. But if a linear acceleration loop is also closed, then the automatic control system will reduce the angle of attack in the same way as does the statically stable airframe.

Design Considerations

Effects of "downwash" and "upwash"

In general, "downwash" reduces static stability and "upwash" increases it. The amount of "downwash" or "upwash" varies nonlinearly with the wing-body angle of attack, making nonlinear compensation techniques necessary in the automatic-control system. Such techniques are not used in contemporary control systems, but they will be mandatory for safe and stable control of advanced aircraft, where high angles of attack are required for high-altitude maneuvers.

A good solution to "downwash" is to create CG-CP coincidence and increase the available angular travel of the horizontal tail. This arrangement assumes the use of a suitable closed-loop automatic control-system to provide the proper amount of dynamic stability.

Inner-loop stability

The question arises: how far ahead of the CG can the CP be moved in the preliminary design phase? Two things limit this movement: the requirement that the sum of the steady-state moments must always be zero, and the inner-loop stability margin that must be maintained. The first of these two limitations is determined by the magnitude of the maneuver required at a particular flight condition, the second by the fact that the airframe is a flexible structure and subject to parasitic (inner-loop) instabilities. The inner-loop stability margin, intimately related to the minimum response time of the maneuver-control system, is determined by the damping loop, because this is the highest-order term fed back through the control element. Since the maneuver-control-system parameter that provides the equivalent of static stability is the integral of the damping term referred to above, the limit of negative static stability is set by the ratio of these two parameters (K_2/K_3) times the airframe's natural angular frequency at the mode in question (assuming the damping term is set at its upper-stability-limit).

Justifying the control system

To achieve the gains outlined above, an automatic-control system is a must. Such a system, designed as a basic component of the airplane, will no doubt be costly. It might be well, therefore, to justify its use on other grounds. Consider the increasing problem of adequate traffic control. In its final solution, this problem will require some type of built-in control system. Another point to remember is that once powered controls become prevalent, and the aircraft-heading loop is closed, closure of the aerodynamic loop becomes merely an elaboration of an existing system.

RELIABILITY OF SERIES-PARALLEL COMBINATIONS

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Author Moan continues with his series of system reliability charts for use with redundant components and subsystems, offering four more for the control engineer's data file. Refer to CDF-2, page 85 of the February issue, for charts of single series strings and of single parallel arrays.

FIG. 1. Reliability of a system of parallel branches vs. the number of series-linked components and the number of parallel branches.

One branch has n components in series, and there are k branches in parallel. Let p_{ij} = reliability of component ij. i = 1, 2, ... , k; j = 1, 2, ... , n. System will fail if all branches fail. The reliability of the system is

$$P_s(n, k) = 1 - (1 - p_{11} \cdot p_{12} \cdots p_{1n}) (1 - p_{21} \cdot p_{22} \cdots p_{2n}) \cdots$$

If the reliability of each component is equal, then

$$P_s(n, k) = 1 - (1 - p^n)^k$$

COMMENTS:

If p is kept constant, then the reliability of the system

a. *deteriorates to 0 with an infinite number of series components even if the number of parallel branches increases without limit.*
b. *approaches 1 if the number of series elements remains finite and the number of parallel branches becomes infinite.*

FIG. 2. Reliability of n groups of k parallel components.

One group has k components in parallel, and there are n groups in series. Let p_{ij} = reliability of component ij. i = 1, 2, ... k; j = 1, 2, ... n. A group will fail if all components within the group fail. The system will fail if one or more groups fail. The reliability of the system is

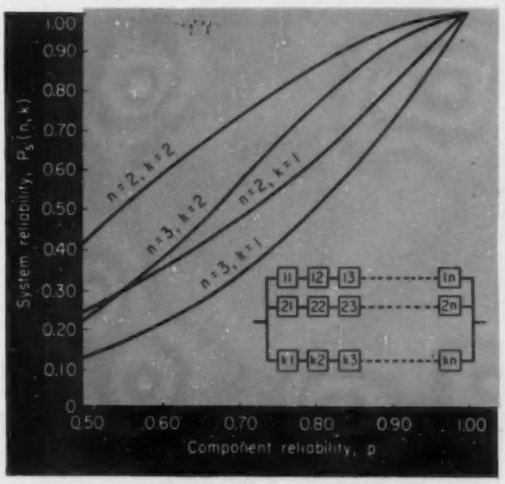
$$P_s(n, k) = [1 - (1 - p_{11})(1 - p_{21}) \cdots (1 - p_{k1})] \cdots [1 - (1 - p_{1n})(1 - p_{12}) \cdots (1 - p_{kn})]$$

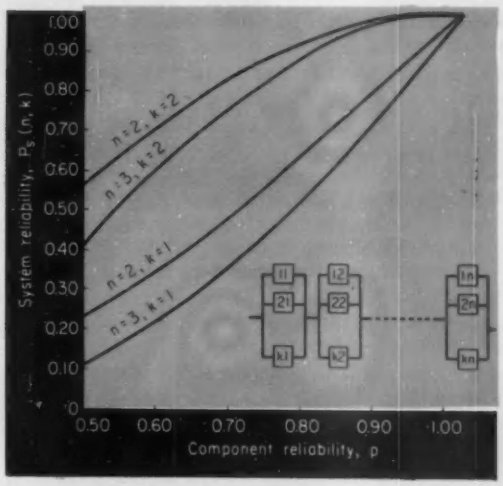
If the reliability of each component is equal, then

$$P_s(n, k) = [1 - (1 - p)^k]^n$$

COMMENTS:

1. *If p is kept constant, then the reliability of the system*
   a. *approaches 1 as k, the number of parallel components, is increased without limit even if the number of series groups approaches infinity.*
   b. *deteriorates to 0 if the number of series groups is increased without limit and the number of parallel components is finite.*
2. *This type of system is much more effective than the system shown in Figure 1.*





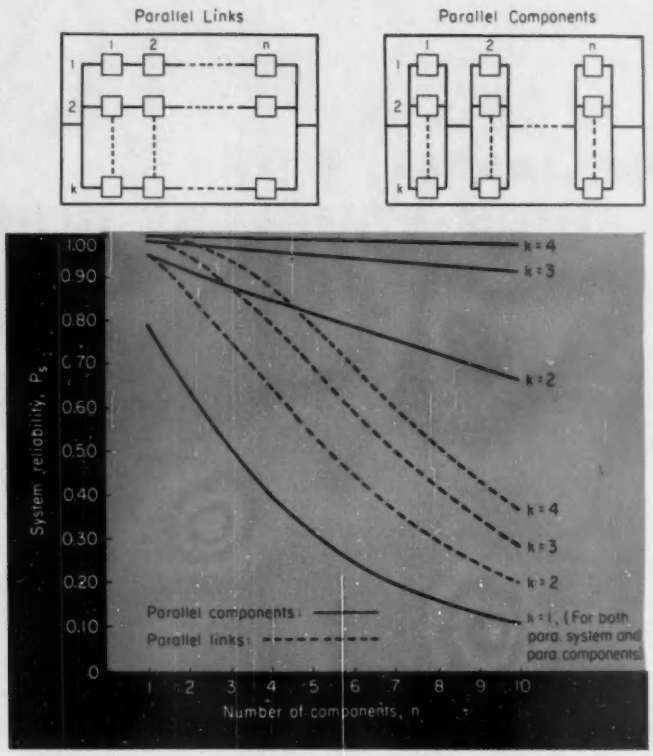


FIG. 3.
System reliability compared for parallel branches and parallel components.

$p = .80$ $\quad P_s = 1 - (1 - p^n)^k$
$k = 1, 2, 3, 4.$
$n = 1, 2, \ldots, 10.$

$p = .80$ $\quad P_s = [1 - (1 - p^k)]^n$
$k = 1, 2, 3, 4.$
$n = 1, 2, \ldots, 10.$

COMMENTS:

Indicates a. how rapidly the reliability of the parallel-component system approaches reasonable values.

b. the slow rate of increase in the reliability of the parallel-branch system.

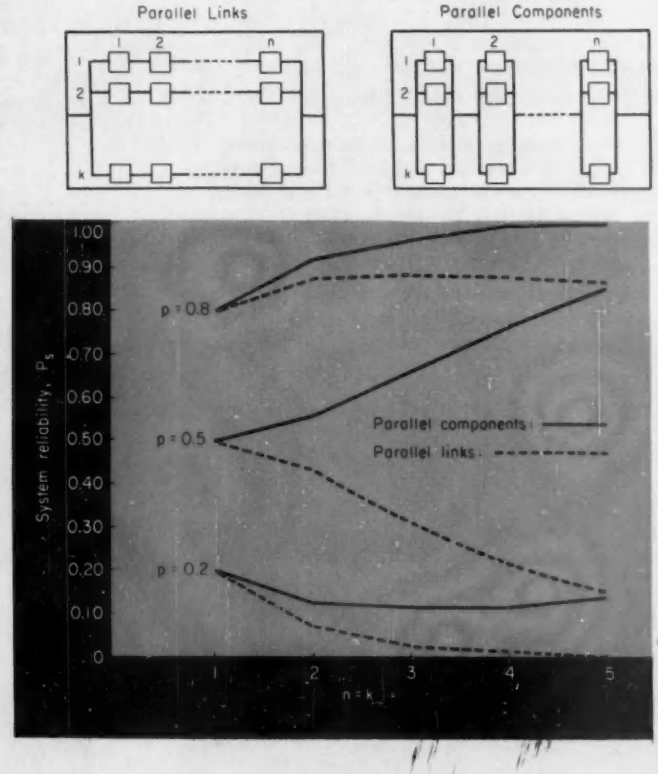


FIG. 4.
System reliability compared for parallel branches and parallel components when $n = k$.

COMMENTS:

1. *This is a special case of Figure 3, where the number of branches equals the number of components in each branch. It shows how the system reliability varies with different values of p.*
2. *Largest divergence between the two systems occurs at p, component reliability, = 0.5.*

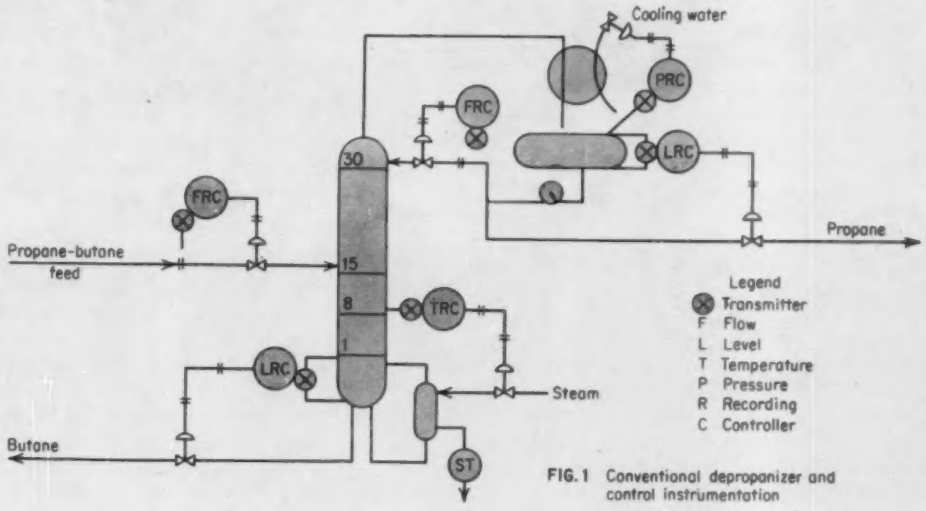


FIG. 1 Conventional depropanizer and control instrumentation

Basic Concepts of Feedback Control

Powell discusses the basic concepts of automatic systems to establish the necessary background for understanding more complicated control problems. The concepts he develops and applies to a refinery process with pneumatic control apply also to other control systems, such as servos, and to processes employing electrical rather than pneumatic signals.

Step by step, he presents a familiar temperature-control system, develops the individual building blocks and the open and closed loop block diagrams. Then the concepts of gain, phase shift, frequency response, and natural resonant frequency are introduced to give the reader a nonmathematical view of these important factors. Finally, these and other concepts are discussed with respect to their practical signficance in selecting controller settings and minimizing the effects of disturbances to the system.

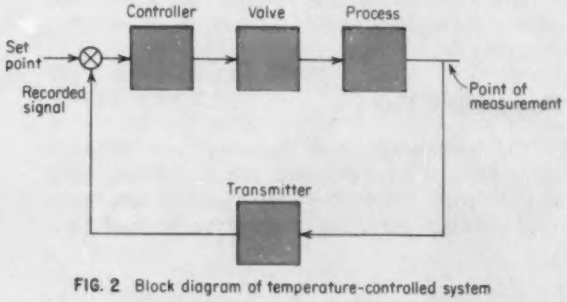


FIG. 2 Block diagram of temperature-controlled system

BRUCE E. POWELL
California Research Corporation

One of the most familiar pieces of equipment in a refinery is the distillation column, a common example of which is the depropanizer, Figure 1. The propane-butane feed enters the middle of the column and is separated into two streams—propane out of the top and butane out of the bottom. Automatic control is used to maintain the necessary process heat and material balances.

Among the variables being controlled on the system shown are temperature, pressure, and flow. Control of the column temperature is important because it adjusts the heat and material balances to compensate for changes in feed composition and feed rate. The temperature control system, therefore, serves as a good model for explaining the basic concepts of automatically controlled systems.

Each component in a controlled system may be represented by a block, and each may then be combined into a system block diagram. The diagram in Figure 2 is the depropanizer's temperature-controlled system. The functioning of the overall system can best be understood by first investigating the functions of the individual components.

Transmitter

The transmitter measures process temperature and regulates a signal, here a pneumatic signal, to be proportional to the temperature. Thus the transmitter has a temperature input (deg F) and a pneumatic output (psi), Figure 3. If the eighth tray

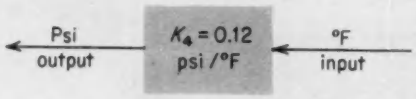


FIG. 3 Transmitter

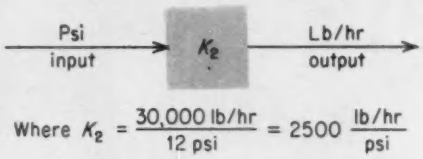


FIG. 4 Control valve

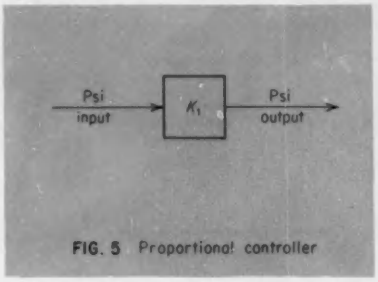


FIG. 5 Proportional controller

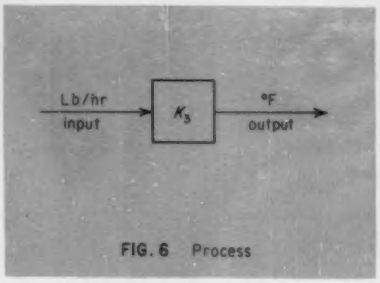


FIG. 6 Process

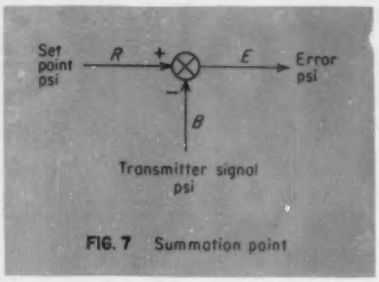


FIG. 7 Summation point

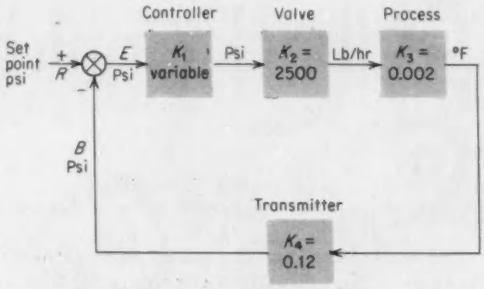


FIG. 8 Closed-loop temperature system block diagram

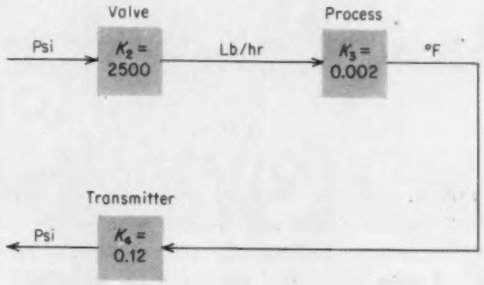


FIG. 9 Open-loop system block diagram, excluding controller

temperature must be kept at a desired 200 deg F temperature, a transmitter might be selected that operates from 150 deg F to 250 deg F, with a resulting span of 100 deg F. The transmitter output changes from 3 psi to 15 psi (an industry-wide standard) for a total of 12 psi for the complete input span. Thus, the ratio K_4 of output to input is 12 psi/100 deg F, or 0.12 psi/deg F. This is known as the gain of the transmitter.

Control Valve

The same approach can be taken to find the gain of the control valve, Figure 4; but here the input is in psi while the output is in lb/hr of steam. Suppose the process requires that a valve pass 30,000 lb of steam/hr in its wide-open position. The valve's gain K_2 then would equal 30,000 lb/hr for 12 psi, or 2,500 lb/hr/psi, assuming a linear characteristic.

Controller

Figure 5 shows the block diagram of the controller, which links the transmitter to the valve. Controller input and output are pressure signals with a range of 3-15 psi. Since the input and output have the same dimensions (psi), the controller gain K_1 is nondimensional. For simplicity, a controller with proportional action only will be considered for this process. The value of K_1 may, therefore, be adjusted by one controller knob and is equal to 100 divided by the proportional band setting.

Process

The process block, Figure 6, represents the reboiler and column. It has an input of lb/hr of steam and an output of deg F. Thus the process gain term K_3 has the dimensions of deg F/lb/hr. Experimental runs usually determine the exact value of K_3; a typical value, however, might be 0.002 deg F/lb/hr for a depropanizer. The reflux rate, the relative volatility between propane and butane, and the number of trays are three important factors affecting the process gain.

Summation Point

The summation point designates the adding or subtracting of two or more signals. In Figure 7, $R - B = E$, where R is a psi signal corresponding to the desired operating temperature (set point), B

is a psi feedback signal coming from the temperature transmitter, and E is a psi error signal. The error signal operates the controller, which continuously tries to reduce to a minimum the deviation of the variable B from the set-point R. This summation point is a physical part of the controller.

Closed-Loop System

Figure 8 repeats the block diagram of Figure 2, but with values and dimensions worked out for the individual components. With all of the components interconnected as shown, the system is known as a closed loop because it provides a continuous path for signals to travel around the loop. Such a system provides the means for reducing the error signal to a minimum. However, with this advantage comes the disadvantage that instability will occur if the controller is set for too high a gain. The feedback would be too large, the error signal would increase rather than decrease, and the variable would oscillate with an ever-increasing amplitude. To avoid instability the controller gain must be reduced enough to provide a safe margin. The operation of this closed loop can be predicted from the operation of only a portion of the closed loop.

Open-Loop System

The procedure is to remove the controller and summation point from the block diagram; this results in an open-loop block diagram, Figure 9, containing the combination of the valve, process, and transmitter. Because the open-loop components in the system are in series, the gain terms may be multiplied to obtain an over-all gain, known as the open-loop gain. Thus, for Figure 9, the open-loop gain K is: $K = K_2K_3K_4 = 2{,}500$ lb/hr/psi x 0.002 deg F/lb/hr x 0.12 psi/deg F $= 6$. This part of the loop has a nondimensional gain similar to the controller's.

Determination of the open-loop gain is an important first step; but it must be identified more completely, particularly as to the effect of frequency on the components and the open-loop system.

A demonstration indicates how frequency affects the gain. Suppose, by using an air-pressure regulator, a change of 1 psi is made at the control valve. As a function of time, this change may be made in many ways, some of which are shown in Figure 10. Although the input signals are different and will cause different transient responses, the output at the new equilibrium condition is the same; at a new equilibrium state, lb/hr, deg F, and psi each reach the same final values. Because $K = 6$ for the open loop, a 1-psi change at the valve causes a 6-psi change at the transmitter output.

The last two examples (d and e) show oscillations in the input and suggest that there is one dominant frequency in the transient input. When the transient dies out, the frequency is zero. Thus, the gains determined above for each of the blocks and the open loop are steady-state or zero-frequency gains. It can be shown that the other input signals, a, b, and c, of Figure 10 are made up of a number of sine waves of different frequencies and that these also die out, allowing the zero-frequency gain to be determined.

The gain $K = 6$ is the open-loop zero-frequency gain, excluding the controller. However, the gain changes if the frequency is not zero. Consider a sinusoidal input to the valve, Figure 11. Here, with a slowly oscillating input of 1 cycle per hr having a 1-psi amplitude, the output, too, is sinusoidal. The frequency is so low it is essentially zero; and, knowing the zero-frequency gain is 6, it follows that the output amplitude from the transmitter will be 6 psi for a 1-psi input amplitude, Figure 12. The ratio of these amplitudes is known as the magnitude ratio.

Another observation that can be made with respect to the input and output signals of Figure 12 is that the peaks and valleys of the two curves occur at the same time; this is known as being in phase. If the input signal with the same 1-psi amplitude increases to a much higher frequency, perhaps one cycle per min, experience and logic indicate that the output of a physical system, such as a distillation column, cannot respond as with a low-frequency signal. The main deterrent to response at high frequencies is the heat capacity of the reboiler and column and the mass of material in the column. Before the full effect of the 1-psi input signal can be felt at the output, the input signal is decreasing. At an ex-

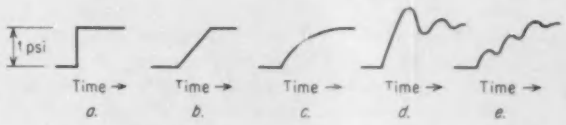


FIG. 10 Air pressure changes to control valve

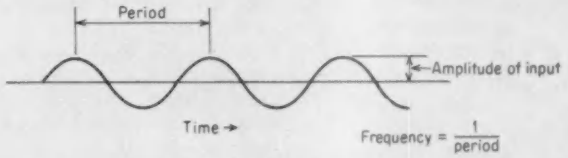


FIG. 11 Sinusoidal input signal used to analyze systems

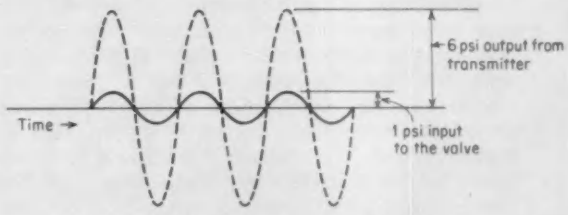


FIG. 12 Open-loop response at low frequency

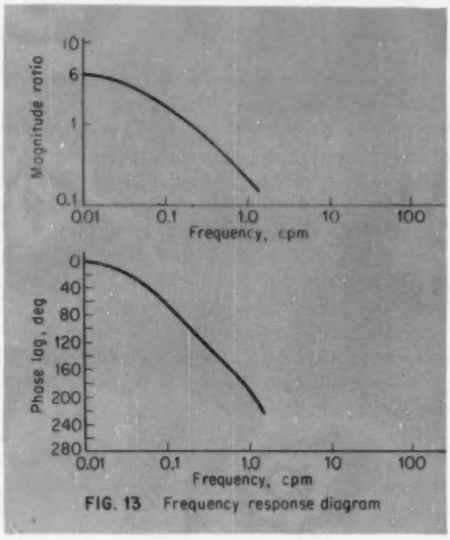


FIG. 13 Frequency response diagram

tremely high input frequency, no effect at all would appear at the output. From this reasoning, it can be concluded that, as the input frequency increases, the output amplitude signal decreases; and, because of the lags in the physical system, the output signal changes phase with respect to the input signal.

For some components of the control loop, the magnitude ratio and phase lag at selected frequencies can be calculated. However, there are many components which are not subject to calculation because of their complex nature. For such a situation, it is best to find the response by testing the system. Figure 13 shows the results of a test on a typical system. This plot of magnitude ratio and phase lag is called a frequency response diagram. The low frequency point was obtained from the traces in Figure 12. At a frequency of 1 cpm, it follows that for an input signal of 1 psi amplitude to the control valve the test results would look like the traces shown in Figure 14. The output amplitude has decreased to one half of the input amplitude, resulting in a magnitude ratio of 1/2. In this case, the output is displaced in time from the input by 1/2 cycle, or 180 deg, and is known as a 180-deg phase lag.

Adding the Controller

The selection of a 180-deg process phase lag in Figure 13 was not an accident--it is a very important condition for any control system. Before taking up this point, however, it is necessary to discuss the controller in more detail. A successful controller must cause corrective action, so that if the column temperature goes up the valve will close to reduce the steam rate. This operation is illustrated in Figure 15, where the set-point pressure is fixed (determined by the desired column temperature) and the transmitter pressure increases as the column temperature rises above the desired temperature. Since the control-valve pressure must decrease as the transmitter pressure increases, there is a reversal of signal in the controller. Figure 16 shows the sinusoidal input to the controller from the transmitter and the controller output signal. In this case K_1 for the proportional controller equals unity. It is the construction of the controller that causes the reversal, or constant 180-deg phase shift, between the two signals at all frequencies of interest.

If the controller is added to the open-loop system, with $K_1 = 1$, Figure 17, and the system is excited at B with a sinusoidal signal from a pneumatic sine wave generator at 1 cpm with a 1-psi amplitude, the system will produce the input-output relationship shown in Figure 18. This differs from Figure 14 because of the reversal of the input signal by the controller. Note that the output is different from the input by minus 360 degrees. Half (180 deg) is due to the phase lag of the process and the other

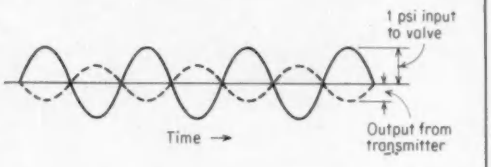


FIG. 14 Input and output records

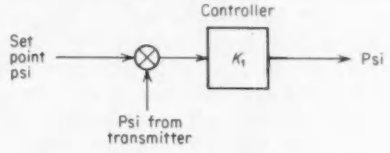


FIG. 15 Summation point and controller

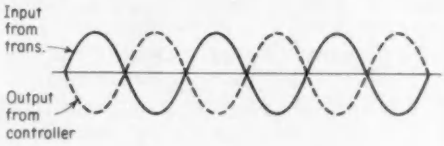


FIG. 16 Phase reversal in controller

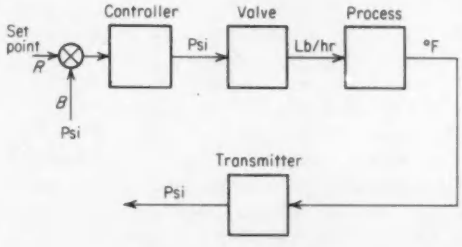


FIG. 17 Open-loop diagram, including controller

half is due to the 180-degree phase shift of the controller. The output is 0.5 psi for the 1-psi input. When controller gain increases to $K = 2$, the open-loop gain equals unity and the input and output coincide exactly, so the generator can be replaced by the transmitter output and the oscillation will continue in the closed loop. This is the situation of any system when it cycles continuously.

Natural Resonant Frequency

Unity gain and minus 360-deg phase shift occur for a particular system at only one frequency, called the natural resonant frequency, f_n. Literature on frequency response often refers to the fact that the natural resonant frequency is found at the point of minus 180 deg of phase lag. This is valid because it is understood that the controller always contributes 180 deg of phase shift and thus leaves the other components to contribute the additional 180 degrees.

Most refinery controlled systems have a natural resonant frequency in the range of 0.05-20 cycles per minute. A system with a high natural resonant frequency recovers rapidly from a disturbance. One with a low resonant frequency recovers slowly from a disturbance. The degree of upset, however, is also dependent upon the nature of the disturbance. Figure 19 shows a slow cyclical disturbance, which appears to have a dominant period of about 45 minutes. This could represent a feed change or a steam-supply-pressure change.

If the response of the distillation column control system is fast, such as $f_n = 0.2$ cpm, or a period of 5 minutes, the system easily corrects for this disturbance with such a small temperature change it would not be noticeable. On the other hand, if the system had a slow natural response (45-minute period) this would not be fast enough to correct for the disturbance. Column temperature would follow the disturbance (Figure 19) and never settle down.

A detailed discussion of why this is true is not within the scope of this article. However, some insight may be gained by looking at the magnitude ratio at the natural resonant frequency and at much lower frequencies. At the natural resonant frequency, the magnitude ratio for the open loop is unity if the controller is adjusted to obtain continuous cycling. To have satisfactory control results, the controller gain should be reduced so that the loop gain would be 0.5 or 0.6 rather than unity. The system is now stable because the feedback signal is progressively reduced until the set-point is closely approached. At smaller gains the system will appear sluggish in response. At much lower frequencies, however, the magnitude ratio is much higher than unity. It follows, then, that disturbances having frequency components lower than the natural resonant frequency cause large corrective signals in the loop to keep the system on control. A small error between the set-point and variable produces a proportional corrective signal from the controller which has more effect in the low frequency region. A (simplified) conclusion can now be stated:

▶ the natural resonant frequency of the controlled system should be as high as possible to correct for disturbances with minimum temperature deviations.

The natural resonant frequency is the primary basis for comparison of alternate systems. For the types of columns where it would apply, column temperature control systems can be compared which have steam, hot oil, or fired heater reboilers. The f_n values for the column pressure and temperature controlled systems will indicate whether interaction of the systems should be expected. Once these factors are known, changes may be possible to overcome the difficulties.

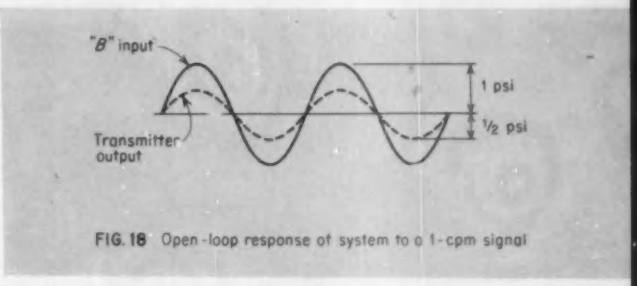


FIG. 18 Open-loop response of system to a 1-cpm signal

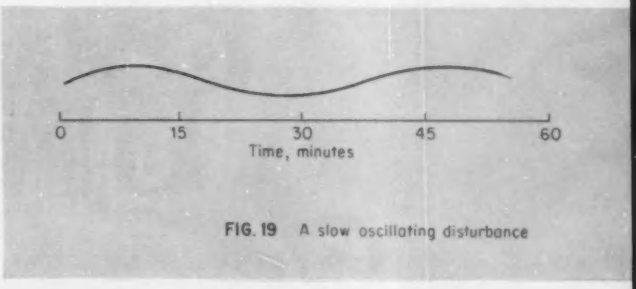


FIG. 19 A slow oscillating disturbance

The process was assumed here to be controlled by a proportional controller. Actually, conventional controllers may have two more actions, those of reset and rate. When these actions are present, they can affect the system's natural resonant frequency. The amounts of proportional, reset, and rate must be selected by relating the knob settings to the natural resonant frequency. With these three controls, an infinite number of combinations can provide a stable system, but only a small range of combinations approach optimum control. Too much reset lowers the allowable proportional gain and can lower the natural resonant frequency of the system by a large amount, thus making it needlessly susceptible to lower frequency disturbances. Too much rate action also lowers the allowable proportional gain and increases the steady state error between set-point and controlled variable. To get the most from a controller, a rough guide is to keep the gain high (total open-loop gain of about 0.5) at the expense of the reset and rate adjustments.

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ANALOG-TO-DIGITAL CONVERTERS

What Ones Are Available and How They Are Used

THE GIST: Business activity and plant operations have become so integrated that it appears only machine methods can assure that appropriate decisions are made. Research and development, too, has become complex: today's large-scale experiments produce quantities of data so enormous that only automatic data-recording devices coupled with fast digital computers seem capable of handling them. And completely automatic processes, master-controlled by digital computers, require that the process parameters be known accurately, immediately, and centrally in a form suitable for digital computation.

For these reasons, the analog-to-digital converter has become an important link in the communication between the analog instruments that measure the physical parameters of experiments and processes, and the digital computer or other data-processing equipment. Author Bower tells how these converters are built, what they can do, how they are integrated into systems, which ones are available, and who makes them.

GEORGE G. BOWER
Riverside Research Laboratory
Motorola, Inc.

Analog-to-digital converters are devices that express the results of measurements as numbers. They play much the same part as a person reading an instrument, but they do it faster, more reliably, and in a form convenient for immediate storage, transmission, or calculation. The parameters of interest are those that characterize the nature of an experiment, or the performance of a design or a process: voltage, current, pressure, flow, length, mass, temperature, Ph, velocity, acceleration, time, frequency, radiation, emanation, force, etc. Since electrical quantities are convenient to handle—arithmetic manipulation and transmission by wire are easy—it is reasonable that many of these parameters be transformed to electrical quantities.

There are many other parameters whose measure and final indication consist of a shaft rotation, without the intervening electrical transformation. It is only natural, therefore, that the history of analog-to-digital converters be primarily concerned with the conversion of these two parameters: electrical voltage and mechanical shaft rotation. To these has been added another convenient pair of reciprocal parameters: frequency and time.

MECHANISM OF CONVERSION

Every measurement is fundamentally based on counting the number of units in a quantity. A whole class of converters uses this principle. The recently developed high-speed electronic counters are particularly well-suited to this application.

Another class makes use of what can be called a comparison principle, involving feedback. Here, the unknown is compared to a series of known values that are accepted or rejected until equality is reached; then the accepted values are summed. The chemist's balance illustrates this.

A third class of converters compares the unknown to an established scale; yardsticks, meter sticks, and tapes are broad examples.

Specific examples of each type will be discussed, but first it is best to cover some of the factors involved in using analog-to-digital converters.

The importance of sampling rate

When analog functions are represented by numbers, one problem is to determine how many samples are required to amply define the function. An experimenter taking data gains an intuitive feel for the rapidity with which a phenomenon is varying, and he varies the number of samples accordingly. But it is not necessary to rely on these intuitive feelings, since most analog functions are confined to finite bands of frequency. Thus, a spectrum analysis of a given function usually indicates that there is a maximum frequency beyond which the spectral energy is negligibly small. A sampling rate of twice this maximum frequency theoretically allows com-

plete reconstruction of the function[1]. Practically, a sampling rate of roughly ten times the highest frequency is found more convenient.

The representation of numbers

A human observer uses the decimal representation of numbers while an automatic system uses a binary number code of base two. The latter allows many simplifications in equipment and is very convenient for transmission, recording, or direct introduction into a digital computer. However, the conventional binary system does suffer from this disadvantage: a long series of binary digits is difficult to read and comprehend. To get around this difficulty, a binary-coded-decimal system is used that retains the biordinal quality of the binary number and yet is fairly simple to read (see "The Cyclic Binary-Decimal Code," CONTROL ENGINEERING, March 1957, page 87). Each digit of a decimal number is represented by four binary digits. Some computers use this scheme; others, using the conventional binary code, require that inputs in binary-coded-decimal form be converted before computation can take place.

FIG. 1. Block diagram of counting-type analog-to-digital converter that accepts frequencies or time intervals as input.

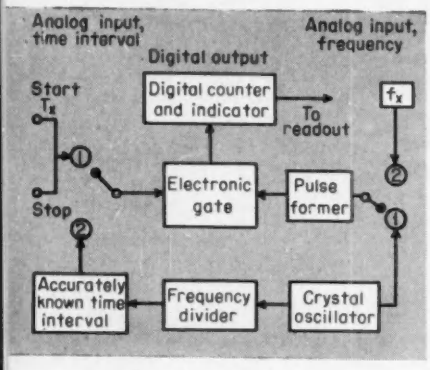
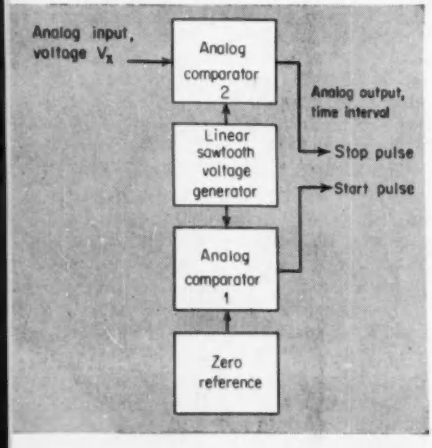


FIG. 2. Transformation of voltage to a time interval making use of linear sawtooth voltage generator and analog comparators.



Another disadvantage of both of these codes affects their use in converters: in going from one number to an adjacent number, many digits change; that is, many ones are replaced by zeros and vice versa. For this reason some types of converters use a permutation of the binary code in which only one change takes place between successive numbers, so that the given number can be mistaken for at most one of its adjacent numbers. The reflected, cyclic, or Gray code[2] is one popular permutation. Other permutations can be obtained that are useful in representing decimal numbers[3, 4]. They help in preventing ambiguity and offer other advantages in converter design.

A question arising in number representation in converters is whether the number should be in serial or parallel form. Serial representation means that the digits are transmitted in time sequence; parallel means that all are transmitted simultaneously. This is essentially a transmission problem: speed is gained by using parallel channels at the expense of providing the extra channels. The system to use depends on the application.

The possibility of multiplexing

In data-processing and control applications requiring many measurements, it is not usually necessary to associate a separate converter with each measuring instrument: equipment can be saved by time-sharing one converter between more than one input. A commutator samples each input in turn and feeds the analog values to the converter, where they are transformed to numbers. This is especially convenient for such analog quantities as voltage, frequency, and time, and can be applied to shaft rotations if angle-repeating transducer systems are used between each shaft and the converter. The converter and commutator must be fast enough so that each input is sampled sufficiently. In control applications the sampling of inputs need not be in cyclic order since particular inputs can be selected at will by the program in a digital computer. Here the inputs are treated much like storage locations in the computer memory.

The accuracy of conversion

Whatever accuracy can be built into the primary measuring instrument can usually be carried through to the number by providing sufficient digits in the number. For example, an accuracy of 1 percent full scale requires two digits in the decimal system, seven in conventional binary, and eight in binary-coded decimal. Greater accuracy requires correspondingly more digits, easily added at the cost of more equipment.

Other characteristics of converters

To the sampling rate, number system, number of digits, and number of channels should be added these characteristics to get a full picture of a converter: analog input, range of inputs, loading effects, type of readout, size, weight, and power.

The analog input refers, of course, to the parameters to be measured and converted to numbers. Converters can be built to handle almost any parameter, but from a system point of view it is usually desirable to deal with only a few so that advantage can be taken of multiplexing.

Transducers are available for performing analog transformations on most parameters and putting them in the form of voltage, shaft rotation, frequency, or time, for which highly developed and versatile converters are available. The Allen B. Du Mont Laboratories has published a helpful compilation of such transducers.

The range of inputs is important in any measuring process. Multi-range conversions are usually achieved by performing analog multiplications on the input before actual conversion. This is especially convenient where the parameter is voltage, since amplifiers and voltage dividers can do this multiplication with good accuracy. Shaft input range can be changed by using gear trains.

Converter loading effects are important because they can reduce the accuracy and response of the measuring instruments. These show up primarily in shaft-position converters, particularly when the shafts are part of the sensitive measuring instruments. Both the torque load and the moment of inertia must be kept small.

Readout equipment varies with the application. Data-reduction operations require typewriters, and card and tape punches. It is also possible to read onto magnetic drums and tape before transferring to these devices. Control applications involving digital computers do not need this equipment if the numbers are placed directly in computer storage.

Size, weight, and power requirements, while not important in stationary systems, are crucial in mobile applications, particularly aircraft.

CONVERTERS THAT COUNT

Best known and most easily recognized counting converter is the

electronic counter. The inputs to this device can be frequency, pulse repetition rate, or the inverse, time. Figure 1 shows a simplified block diagram. The principal functional parts are an electronic gate, a counter and indicator (it may be decimal, binary, or binary-coded decimal), a crystal oscillator, a pulse former, and frequency dividers. To measure a time interval, place the switches in position 1. A pulse representing the start of the time interval opens the gate and allows accurately timed pulses from the crystal oscillator and pulse former to enter the counter. These are added up one by one until a pulse representing the end of the time interval closes the gate. The total count is a measure of the time interval.

For measuring frequencies or pulse repetition rates, throw the switch to position 2. An accurately known time interval derived from the crystal oscillator by frequency division opens the gate, allows the unknown frequency to be counted for the specified time, and then closes the gate.

The total appearing in the counter can be read on glowing neon lights, or can be fed directly into a computer. Self-contained instruments based on this principle are made by many companies, including Berkeley Scientific Co., Hewlett-Packard Co., and Potter Instrument Co.

Counting rates at present are up to 10 mc. When diffused-base transistors become available, a rate as high as 25 mc may be practicable.

The principle shown here forms the heart of other analog-to-digital converters that make use of analog transformations to change voltage, shaft position, etc., to either a time interval or a frequency.

Chief among these is the Millisadic, manufactured by Consolidated Electrodynamics Corp., which accepts a voltage input as well as a pulse duration and a pulse train input. The latter two are handled in the manner just described, while the voltage input is handled as shown in Figure 2. A linear sweep voltage is generated by integrating a rectangular pulse, and then fed to two comparison circuits. In the first circuit, a start pulse is generated when the sweep voltage passes through zero reference, allowing a 2.5-mc wave train to enter a counter. In the second circuit, the sweep is compared to the unknown analog voltage, and when equality is reached a stop pulse is generated that prevents further accumulation of pulses in the counter. An accuracy of 0.1 percent of full scale is obtained. The converter is combined with a control unit that allows self-synchronous or externally synchronized operation,

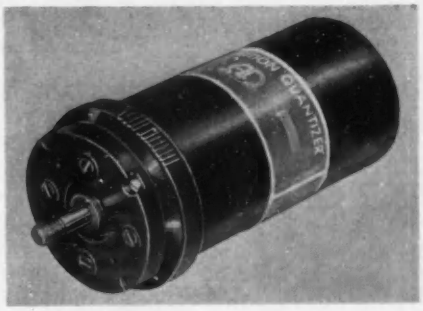


FIG. 3. Austin Co. angular-position quantizer.

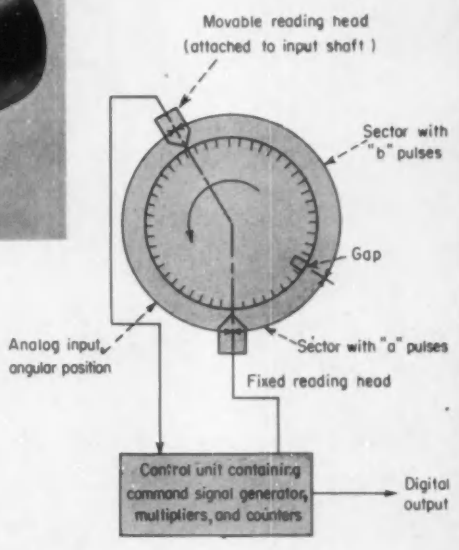


FIG. 4. Simplified diagram showing operation of converter pictured in Figure 3. Shaft position is determined by a counting operation.

a commutator that permits multiplexing of 100 channels at a sampling rate of 400 channels per second, a dc amplifier that permits a variety of input voltage ranges, and storage facilities. The aggregate forms a versatile and flexible data-processing system.

In a system of this type, stability and accuracy depend on two very crucial parts: the sweep generator and the comparison circuits. An excellent paper from Bell Telephone Laboratories discusses these problems and their solution[6]. It was found possible to achieve an accuracy of one part in 4,000 by using transistorized operational amplifiers, the latter forming the major part of the comparators and integrators.

Before leaving the subject of encoding by counting, two other systems should be mentioned, both of which have shaft angular position as a primary input. To solve a gunfire control problem, Stavid Engineering Co. mounted synchros on shafts, obtaining from these synchros a sine wave voltage which is shifted in phase from a reference voltage proportional to shaft rotation. The phase difference is converted to a time interval, which is then encoded in the usual manner. Their system was designed to monitor a maximum of nine dual-speed synchro orders. The results are either recorded on magnetic tape from which cards are prepared, or fed directly to a computer.

Austin Co.'s converter, Figure 3, uses quite a different scheme. It consists of a 3,600-rpm synchronous motor driving two engraved generating discs rigidly coupled together, a fixed magnetic reading head positioned to read marks on one disc, a movable head free to rotate with the input shaft and positioned to read marks on the other disc, and a separate control unit. Each disc is divided into 500 parts: 499 engraved marks and one reference-position gap.

The angular position of the movable head with respect to the fixed head defines the position of the input shaft, Figure 4. This position is determined by counting the marks between the gap and the fixed head on the first disc, and the marks on the second disc between the movable head and the gap, adding the two, and then subtracting the sum from the total number of marks on a disc. This is done on a command from the control unit, which also contains the counters and frequency multipliers. Pulses read by the head are multiplied by eight and then fed to the counters. This permits a resolution of one part in 4,000 at a sampling rate of 60 per second.

CONVERTERS THAT COMPARE

Another class of converters uses a servo-type arrangement to build up known values of a parameter until the sum of these values agrees with the parameter being measured. The J. B. Rea converter is typical of this type. Figure 5 shows a block diagram, and

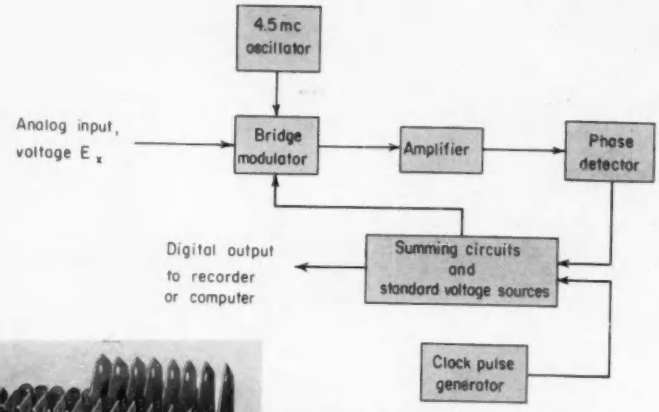


FIG. 5. The J. B. Rea converter uses comparison principle in a servo arrangement with weighted voltage sources.

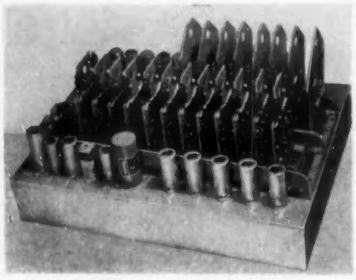
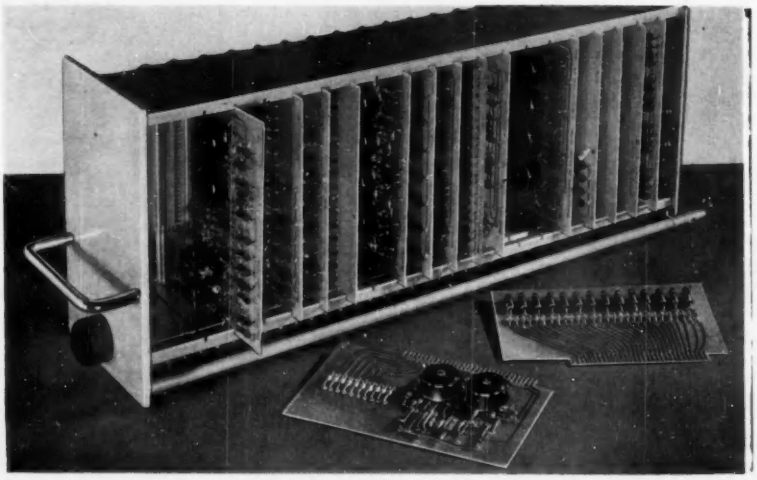


FIG. 6. Converter of Figure 5; features high sampling rate and provision for a variety of coded outputs.

Figure 6 a picture. Functional parts include a bridge modulator, oscillator, amplifier, phase detector, summing circuits, and clock-pulse generator. The analog voltage input is combined in a bridge modulator with an analog voltage derived from the feedback circuit. The modulator serves a dual function: it converts the error signal derived from this mixture to a high frequency so that an ac amplifier can be used following the modulator instead of a stable dc amplifier, and it also causes a phase transition in the error signal when this signal passes through zero, which can be easily recognized in the phase detector. The phase detector controls the action of the summing circuits where the number representing the input voltage is formed.

The summing circuit consists of 13 very accurate voltage sources, each source being assigned a number. The value of these sources can be set at will to fit any arbitrary scale or range. By selecting various combinations of the sources during operation, their sum is made to match the input voltage presented to the converter. The procedure is as follows: The clock pulse turns on the first, and largest, voltage source. If the input voltage is larger than this, the phase detector locks this voltage on; if it is smaller, the phase detector turns it off. A second clock pulse turns on the second source and this is added to the first (if the first is on). If the sum is smaller than the input, the phase detector locks the second source on; if larger, it turns it off. This procedure is continued at each clock pulse until equality is reached. The sources finally selected to match a given input denote a digital number that can be read out in the usual manner.

FIG. 7. Beckman converter features transistor and magnetic-core circuitry for good reliability.



The smallest source is assigned the number one; the others are chosen to match the binary, binary-coded decimal, octal, or other desired code. These sources permit a $\pm 1{,}000$ scale when using binary-coded decimal, or $\pm 2^{12}$ when using conventional binary. The clock frequency can be on the order of 1 mc, so that complete conversion can be made in about 13 microsec. A few more microseconds are usually allowed for control functions.

The J. B. Rea Co. has integrated its converter into a complete data processor called the Series 100 System. By adding a standard fm discriminator and low-pass filter to convert the input from frequency to voltage, this system will accept tape-recorded data from fm-fm telemetering systems. The outputs from pulse-width-modulation telemetering can be fed in directly. Internal programmed conversion rates of 10, 100, and 1,000 per second are provided, or the conversion can be synchronized with an external 100-cps time signal or with any other external pulse rate, such as timing signals recorded on magnetic tape.

For high-speed conversion, a sampling rate of up to 10,000 per second can be achieved, and commutation facilities for time-sharing the converter among a number of inputs are available. Bookkeeping operations, like run identification and calibration information, also are included.

The Beckman Model 112 Data Processor Converter, Figure 7, also makes use of this principle. Numbers are generated in a binary-coded decimal system using 2421 weighting, from which nine's complements are easily obtained. This converter is integrated into a data system that will be discussed later.

The Epsco Co. makes a converter (Datrac, Model B—Figure 8) similar in principle and quite similar in characteristics to the Rea converter. Epsco also made another type (Model A) which has been discontinued. It illustrates a variation on the subtraction or feedback principle[8], Figure 9. The Model-A converter consists of a pulsed comparator, a 200-kc clock, a decision unit, a forward-backward

electronic counter, and a digital-to-voltage converter. With the aid of the digital-to-analog voltage conversion network, a number in the counter generates a proportional voltage, which is compared to the unknown input voltage in the comparator. A clock pulse then drives the counter forward or backward one pulse depending on whether the unknown is greater or less than the fed-back voltage. This increases or decreases the fed-back voltage by one unit and the comparison is made again. Succeeding clock pulses drive the counter until equality is reached. If the input voltage changes, the counter follows and represents the true voltage as long as the input does not vary faster than 1 unit per 5 microsec. If the variation is faster, the counter will lag until the input slows sufficiently for it to catch up. The primary difference between this converter and the Rea and other Epsco converters is that the voltage equality is brought about by adding a unit at a time rather than by processing through a weighted sequence of values.

Similar principles are used in the digital voltmeters of Electro Instruments, Figure 10, and Non-Linear Systems, Inc., Figure 11. The readout technique of these devices is interesting in that each digit position consists of 10 square lucite plates stacked together. The plates are engraved with the decimal numerals zero through nine, and a lamp at the edge of each plate lights as the particular readout value is called for. Contact closures are also provided so that printers may be operated.

Another variation on the comparison principle, described by Zweizig[9], consists essentially of a programmed attenuator which creates an equality between a transducer voltage and a reference voltage. The same carrier supply feeds both transducer and reference, eliminating the problem of maintaining a standard reference.

Still another offshoot of this principle is an ingenious converter described by Smith[10]. In this scheme, Figure 12, parallel digital outputs are obtained without timing, synchronizing, or resetting operations. The converter consists of cascaded one-bit coder-decoder stages, each of which generates a code if the value fed to that stage is greater than the weighted value of that stage, and refrains from doing so if it is less. Each stage also passes on to the next stage the difference between its input and the weighted value of the stage in the first case, or its input with no subtraction in the second case. A variety of codes can be generated by properly designing the stages.

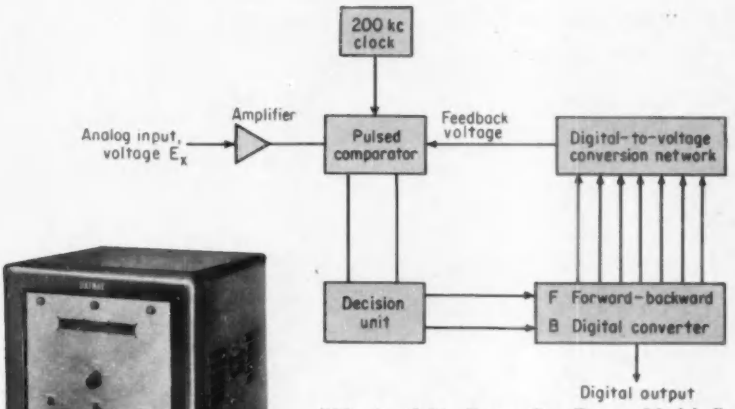


FIG. 8. (left) Epsco Co. Datrac Model B; features high sampling rate and high accuracy.

FIG. 9. (top) Epsco Co. Model A, compares and secures equality between known and unknown voltages by changing known voltage one unit at a time. Model has been discontinued.

TWO DIGITAL VOLTMETERS

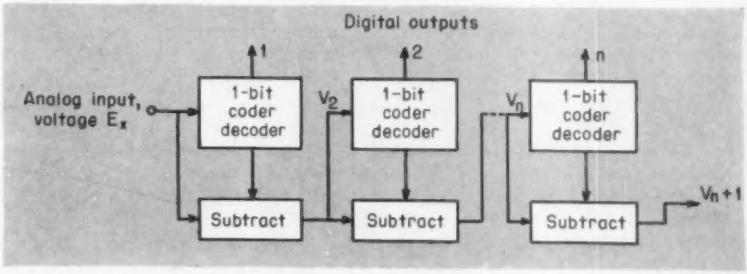


FIG. 10. Electro Instruments

FIG. 11. Non-Linear Systems. Both feature good visual readout.



FIG. 12. Cascaded one-bit coders that eliminate need for timing, synchronizing, and resetting (see reference 10).



CONVERTERS THAT READ

The devices for converting shaft-angular position or linear position associate numbers with a circular or linear digital scale. Many of these are available commercially, and the majority of them rely on a coded disc that rotates with the shaft whose position is to be measured.

The disc is divided into equal sectors, the number of sectors depending on the desired precision, and concentric annular rings are laid out starting at the periphery and working inward. The areas formed by the rings intersecting the sectors are the digits in a binary code, and the number corresponding to shaft position is read radially along a sector. The areas are left clear or made opaque if optical readout is intended, or are made insulating or conducting for brush readout. A photocell or brush is associated with each ring. Figure 13 shows a typical disc.

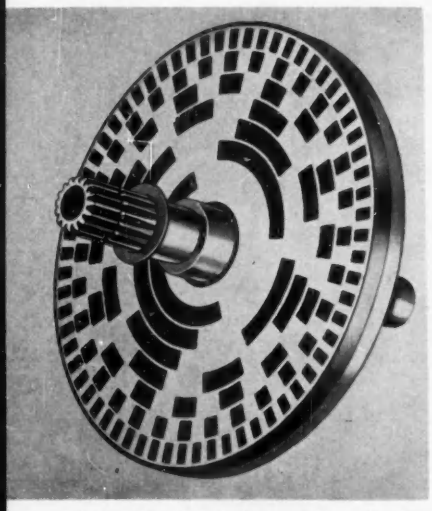


FIG. 13. Typical binary-coded disc for brush readout (courtesy of Librascope).

Photocells and light sources for optical readout, and brushes for electrical readout, are of finite size. If the disc is located so that the readout devices are positioned at the center of a given sector there is no problem, but if the disc is misaligned, the photocells or brushes may straddle two sectors with resulting ambiguity. This can be serious if a conventional binary code is used, since a given sector may be mistaken for one far away from it, yielding a large error.

One solution is to use the cyclic code in which only one digit changes in going from one sector to the next, giving a maximum reading error of one quantum distance. The chief disadvantage is that the number is not in a form that can be immediately inserted into typewriters, punches, or computers. For typewriters and punches, the necessary translator is generally supplied. A digital computer can be programmed to do its own translating.

Commercial units are made by Baldwin Piano Co., Electronics Corp. of America, Giannini, Librascope, W. & L. E. Gurley Co., and Wang Laboratories, Inc. Two of these are shown in Figure 14. Precision dividing machines are required for laying out the sectors on high-resolution discs, but once laid out they can be reproduced photographically. Baldwin Piano Co. has automated the process by controlling the dividing machine from a program on punched cards. Not only linear functions, but nonlinear ones, too, can be laid out; sine and cosine functions are examples.

The output leads of several converters can be connected in parallel, and a specified converter read out by energizing the brushes, flashing a lamp, or pulsing the photocells of that particular converter. Solid-state diodes can be used to isolate the converters from each other where parallel connections are made.

Another way to solve the ambiguity problem on these discs and still allow readout in conventional binary code is to use two specially-positioned readout devices, connected so that priority is assigned to one set or the other according to a logical scheme that prevents ambiguity. These methods are described in the references[13, 13, 14]. Commercial units are made by Coleman Engineering Co., Librascope, Norden-Ketay Corp, and Wang Laboratories. Figure 15 shows two of them.

The precision obtainable on a single disc is limited by the size of the smallest code element that can reliably be resolved. This in turn depends on the size of the discs, the resolution of the readout system, and the wear in the disc-support-shaft bearings. As many as 16 rings (equivalent to a 16-digit binary number or about one part in 64,000) have been placed on discs of roughly 8 to 10 in. in diameter, while 13 rings have been placed on discs of roughly 3 to 6 in. in diameter. Multiple discs can also be used, with the shafts carrying the discs connected in tandem through proper-ratio gear trains. Here, precision is limited by the backlash in the connecting gears unless special anti-backlash precautions are taken.

Somewhat similar in principle, but differing greatly in configuration, are the mechanical converters supplied commercially by Dayton Instruments, Fischer & Porter, Genisco, and Taller & Cooper, Figure 16. These devices depend on cams, star wheels, and similar mechanical detenting mechanisms to eliminate ambiguity. In some, these are brought into play only during readout, so that the shaft must be stationary at this time or the device will be damaged. In others, there is no damage but the required torque increases.

Since almost any electrical meter causes a shaft to position a pointer on a scale, these instruments are particularly adaptable to techniques of the type just described. Assembly Products, Inc., has developed a converter based on a D'Arsonval meter movement. Instead of the usual scale, a printed-circuit board consisting of several concentric arcs broken into coded segments is provided. The needle of the meter is free to move until a "read" signal is received. This energizes a coil, pulling a "clamper" bar against the pointer and pushing it into the coded scale. Only those segments under the needle are energized, producing a code group corresponding to needle deflection.

The Pacific Div. of the Bendix Aviation Corp. has developed a device based on a somewhat similar idea, but using optical readout and not interfering with the meter movement. This is done at a cost of more gadgetry, including a small motor whose shaft carries a photocell, a light-source assembly, and a coded disc. Also forming part of the device is a small mirror placed behind the needle in the meter, a sensitive relay, and a group of storage relays. The reading assembly is mounted facing the meter. The rotating light source produces a beam that is reflected back to the photocell until the beam is broken by the meter pointer. This causes the sensitive relay to drop out and a reading is taken. The position of the coded disc, giving a measure of pointer position, is sensed by brushes and fed to storage relays. From there, the number can be transmitted to distant locations in serial or parallel form.

Since many parameters can be measured as a deflection on electrical meters, these two devices can be used in many applications. Accuracies of roughly 1 percent are claimed.

SYSTEM CONSIDERATIONS

The choice of a particular converter can rarely be made on the merits of the device alone since it is usually used in complex systems and therefore must be compatible with other elements and requirements of the system.

Systems that use converters can be divided into four broad classes:

1. Single-channel systems.

2. Multichannel data-processing systems, where the input is usually (but not necessarily) available in the form of analog data stored on paper charts or magnetic tapes, and where the output is intended for analysis with or without further processing in a digital computer.

3. Multichannel data-processing and semi-automatic control systems where the input is supplied directly from the parameters of the process and where a part of the output is intended for immediate use by the operators of the process and part is retained for additional analysis, with or without further manipulation in a computer.

4. Multichannel, real-time control of processes, with little or no operator intervention. The master controller is a digital computer in this case.

Typical examples of the first class are the electronic track scales made by Cox & Stephens, and the weighing devices supplied by the Streeter-Amet Corp. Extreme speeds are not required, but the devices should be rugged and should not need skilled maintenance.

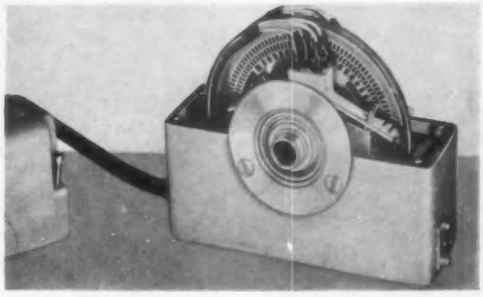
The second class includes those systems usually associated with large-scale experiments. Missile and aircraft flight tests, wind-tunnel tests, evaluations of fire-control systems and jet engines, etc., are typical examples. The data-processing systems manufactured by J. B. Rea, Consolidated Electrodynamics, Benson-Lehner, Librascope, and Telecomputing are intended primarily for these applications. Although the experiments do not take much time, the data collected are enormous, so that the chief demands on the conversion systems are speed and versatility, with size and weight of no great consequence. Long-term reliability, although important, is not paramount, since the duty cycle is generally not high, and time during the lulls can be spent in maintaining the equipment for the peak loads.

Systems in the third class must operate very reliably over long periods because they are monitoring and providing control information on continuous processes, and thus their requirements are different. More important here, too, are features that allow easy communication with the operators, who are more familiar with the process than with the data-processing system. Numbers should be displayed in the decimal system in the units of the process, scale factors and sequencing of parameter readings should be easily set up, and alarms indicating drift of parameters out of tolerance are desirable. Extreme speeds are not required, and size and weight are not particularly important.

FIG. 14. CODED-DISC CONVERTERS THAT USE THE CYCLIC CODE.



A—Baldwin's features high precision, small size, steady light source.

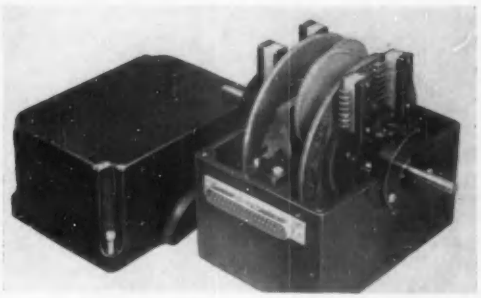


B—Giannini's converter.

FIG. 15. CONVERTERS THAT USE DUAL READING HEADS



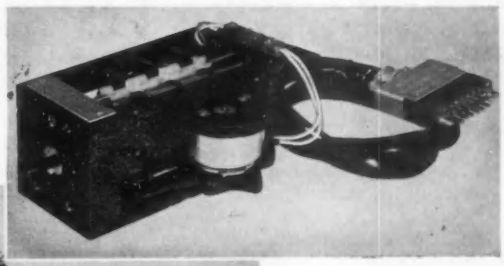
A—Librascope's sine-cosine unit.

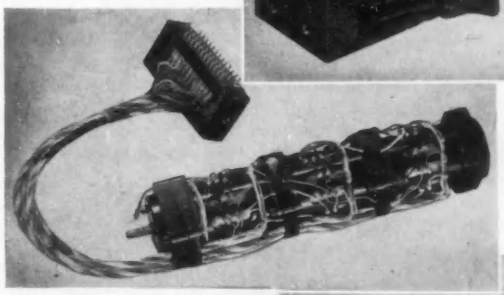


B—Wang angular-position coding system.

FIG. 16. MECHANICAL CONVERTERS

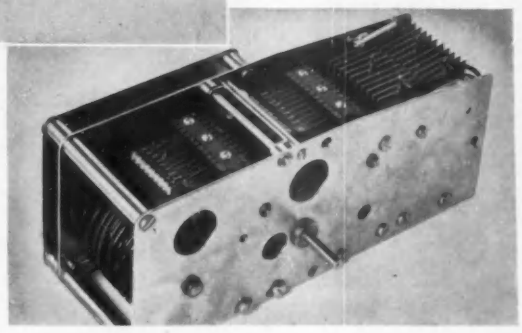
A—Dayton Instruments





B—Genisco

C—Fischer & Porter



Control of chemical plants, petroleum processing, atomic piles, electric-power generation, and steel making are a natural market for systems in this class. A good example of such a system is the Beckman Model 112 Data System; similar equipments are supplied by Fischer & Porter, Panellit, Metrotype, Taylor, etc.

The fourth and last class is the field of the future. How far in the future is anybody's guess, but as concrete evidence of interest and activity in this area, Remington-Rand, IBM, and Burroughs have all set up process-control groups to study the application of digital computers to the control of chemical, petroleum, and manufacturing processes. Also included in this class are a large number of military control operations, ranging from applications where data on the deployment and movement of hostile forces and their weapons are gathered and used in planning a balanced defense and the dispatch of counter-weapons, to the control of a single airplane for navigation and fire-control purposes. Speed, accuracy, and utmost reliability must often be obtained with minimum size, weight, and power under rigorous environmental conditions. Easy communication between the data system and its operator is not so vital in this case, for the data system and the digital computer must communicate back to the process. But this requires the inverse of analog-to-digital conversion—digital-to-analog conversion. Numbers expressing desired parameters for the process derived in the computer must result in the turning of control shafts, providing proper control voltages, etc. Brief examples of this are given later.

There are two philosophies in applying converters to systems. One school of thought holds that a converter should be as close to the fundamental measurement as possible, thereby minimizing the compounding of errors by analog transformations. Multiplexing and any necessary corrections are done on a digital basis.

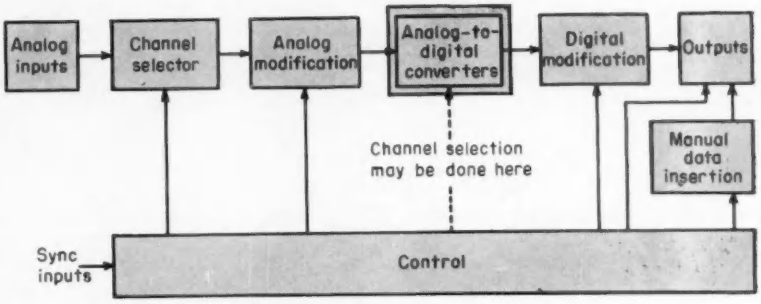


FIG. 17. Functional block diagram of data-processing system, showing place of analog-to-digital converter.

This position has merit, particularly where extremely high accuracies are required, or where the information must be transmitted long distances and thereby face degradation due to transmission medium variations and the introduction of noise. Pulse code modulation systems are meant specifically for this purpose.

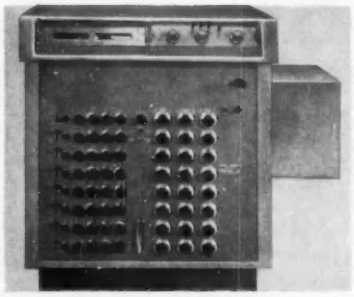
However, the price paid in overall size, weight, and reduction in reliability due to the multiplicity of converters and associated equipment has so far limited the strict application of this philosophy, particularly in airborne telemetering. Frequency modulation coupled with a variety of pulse techniques is used to overcome transmission difficulties, and analog quantities are transmitted. Future developments may change this. In any case, land-based facilities, not being hampered by weight limitations, can use digital transmission.

The other school of thought holds that it is more advantageous to provide one, or at most a few, converters and multiplex on an analog basis. Analog transformations are freely introduced to bring all inputs down to one or a few parameters, to introduce scale factors and zero corrections, to correct for nonlinearities in the sensing instruments, and to filter out unwanted frequency components. The merit of this view is that it is often more economical in equipment, more versatile, more flexible, and not so demanding of computer time in making corrections. In most applications, the accuracy is good enough.

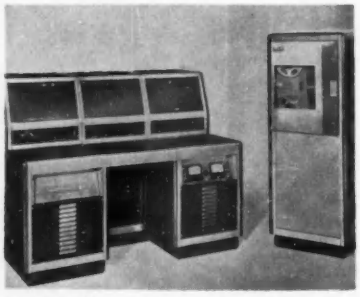
TYPICAL SYSTEMS

The functional block diagram of Figure 17 represents the first three classes of systems and shows the place occupied by the analog-to-digital converter in these systems. The analog inputs enter at the upper left. These are chosen one at a time in sequence by the channel selector, which is driven by the control unit or programmer. From the channel selector, the information passes to the analog modification unit, where a great variety of operations may be performed, such as scaling (multiplication or division), zero offset, linearization, upper and lower parameter alarms, zero elimination, and temperature and pressure compensation. Since the same treatment is not required on all channels, these operations must be coordinated with the channel selector. From the analog modification unit, the information passes to the converter where numbers are generated. After possibly further digital modification, the numbers pass to the output units, consisting of electric typewriters, card and tape punches, and magnetic-tape stores. Specific details of the data being processed can be inserted manually.

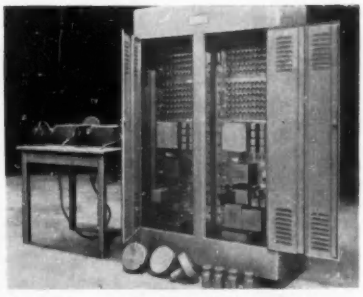
FIG. 18. PACKAGED DATA-PROCESSING SYSTEMS



A—Benson-Lehner decimal converter.



B—J. B. Rea data-processing system.



C—Beckman Model 112 Data System.

Systems produced by many of the companies listed follow this general pattern. Some include more operations than others. Those produced by Benson-Lehner and Telecomputing are meant specifically for the reduction of graphical data, although they are not limited to that. Among the more elaborate, in terms of number of channels and operations performed, are the systems produced by Radiation, Inc., J. B. Rea and Consolidated Electrodynamics, which are meant for the reduction of telemetered tape records and the monitoring of large-scale experiments.

The Beckman Model 112 is another elaborate system, with many features that make it appropriate for "on-line" industrial control applications. It performs the operations indicated on Figure 17 in a versatile, flexible, and easily programmed manner. The treatment to be accorded each channel is set digitally; that is, pins are placed in a plugboard divided into areas according to the operations to be performed. Both analog and digital modifications can be programmed by setting these pins.

Librascope has developed a system using coded-disc converters that differs from the previous ones in that multiplexing is done on a digital basis[15]. Incoming data are secured by synchro transmission. The synchros in turn position disc converters, which are sampled in sequence and the results fed to output equipment. Figure 18 shows some of these systems.

DIGITAL CONTROL SYSTEMS

The systems that have been described thus far are meant primarily for data processing and for control with the aid of human operators. But converters are also used in completely automatic systems where a digital computer assays the data, arrives at decisions in accordance with programmed criteria of performance, and then executes the decisions by feeding control signals back to the process. Figure 19 shows a functional block diagram of a typical system. The process parameters enter on the left and are converted to numbers in the converter (or converters). The numbers then enter the digital computer where they are operated on in accordance with a stored program. The results, converted back to analog quantities in digital-to-analog converters, then turn shafts, throw switches, or do whatever is required. The order of input interrogation and output delivery need not be sequential, but can vary with the demands of the process and the computer program. The industrial application of these techniques is still primarily in the investigation stage.

However, in the military field, much work has been done and some material has been published which shows the possibilities. The chief application on which information is available is aircraft flight control. Most of the emphasis has been on navigation[16], but consideration has also been given to autopilot functions[17], and other operations[18]. In navigation applications, a vast amount of data is generated by aircraft instruments, Loran equipment, surveillance radar, Doppler radar, inertial gear[19], etc., and appears as shaft rotations, time intervals, frequencies, and pulse rates, all of which must be converted to numbers for use by the computer. The computer must solve not only the equations for spherical navigation, but also those relating to positioning of antennas, derivation of Doppler velocities, corrections applied to the inertial gear for centripetal and Coriolis accelerations due to the rotation of the earth, and travel over the earth. The results must then be converted to analog form for control purposes. Most of the types of converters described previously have been used in these applications, although often they have been redesigned consistent with aircraft requirements.

Digital-to-analog conversion

Since digital computer control requires digital-to-analog conversion, it is interesting to look at a few ways to do this. Suppose a number representing a time interval is placed in a counter. A pulse indicating the start of a time interval opens a gate admitting pulses with a known repetition rate to the counter, driving it towards zero. When zero is reached, the counter emits a pulse signifying the end of the time interval.

If a number represents a voltage, the step described above is performed first and the resulting time interval applied to a gate that turns on an accurately-known voltage. This voltage is applied to a capacitor for the proper time interval and the capacitor

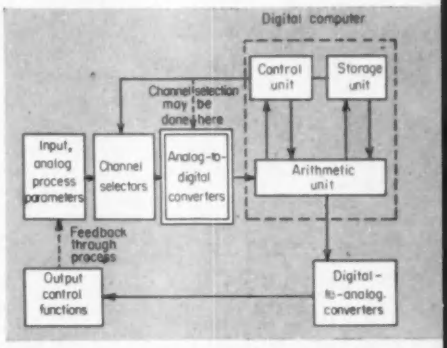


FIG. 19. Functional block diagram of digital control system, showing place of the analog-to-digital converter.

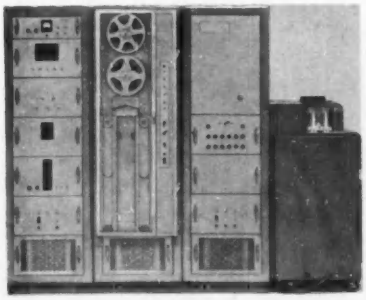
is charged to a value proportional to the number. Alternatively, the number can be placed in a register equipped with a resistance matrix. The matrix weights each stage of the register corresponding to the digit value of the stage. A voltage source connected to the matrix then results in a series of currents whose sum is proportional to the number. This scheme is also used in analog-to-digital converters that use feedback.

If a number represents a shaft angular position, it can be decoded to a voltage which is used as the input to a shaft-positioning servo. Alternatively, a digital servo could be used. For example, a coded-disc converter can be attached to the shaft that is to be positioned. The number derived from this converter is placed in a register where it is compared with the desired number in another register. The shaft is driven until the two are equal.

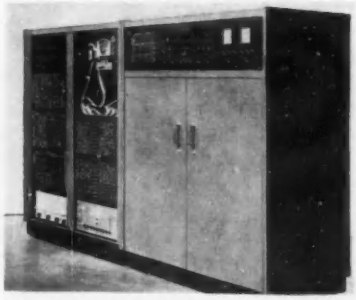
These examples do not exhaust the possibilities.

AVAILABLE CONVERTERS

The preceding discussion showed why converters are needed, how some



D—Giannini recording system.



E—Consolidated Electrodynamics Millisad

have been built, and where they are found in typical systems. The choice of a converter must take into account the variety of parameters involved in an application, the number of channels needed, the sampling rate required, the number system which is most appropriate, the precision required, and the size, weight, and power that can be tolerated. Commercially available converters, together with their characteristics and their manufacturers are listed in Tables I and II. These, plus the descriptions of existing systems showing the types of converters used, will be helpful to those planning new systems.

Not included in the compilation are the frequency meters and time-interval meters using electronic counters, which are produced by Hewlett-Packard, Potter, Berkeley, and a number of other companies. Information on these is quite widespread and easily available. Also omitted are some devices, which though interesting and appropriate, are not commercially available. One makes use of an electron beam deflection tube to provide high sampling rates[20,21].

Only a limited bibliography is presented here. A more complete bibliography can be found in a paper by Fletcher and Walker[22].

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COMMERCIALLY AVAILABLE ANALOG-TO-DIGITAL CONVERTERS

TABLE I – ANGULAR-POSITION INPUT

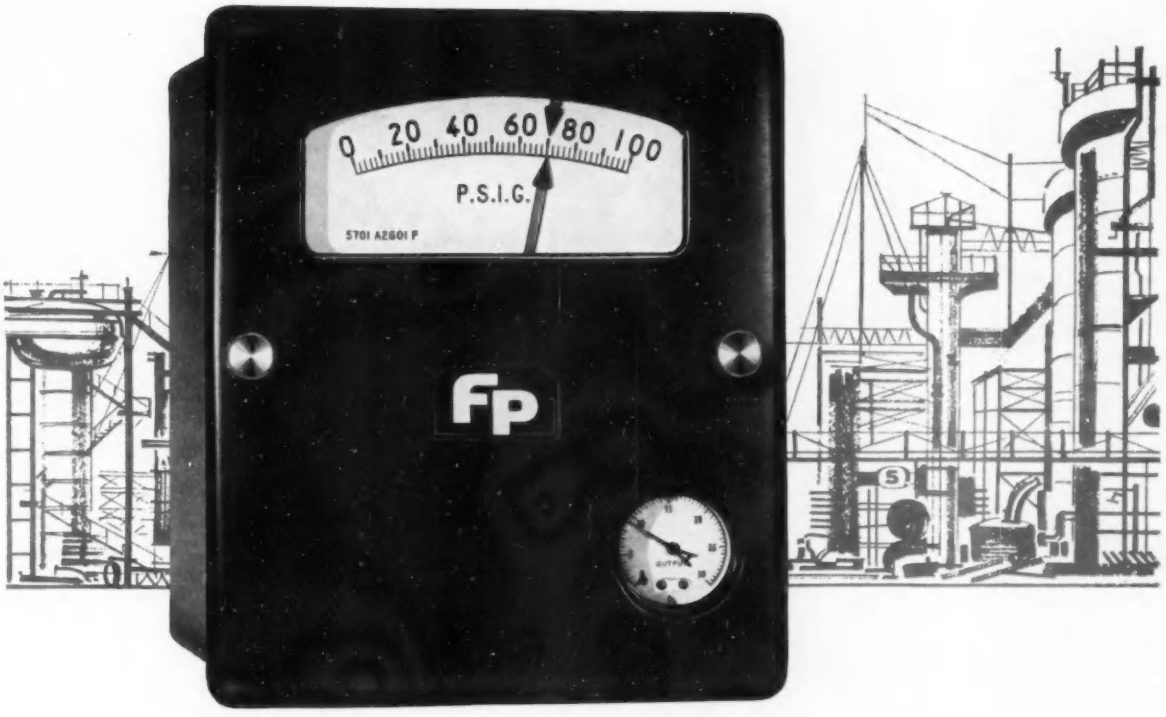
Supplier	Model	Number system	Digits	Accuracy	Sampling rate	Torque		Inertia	Size	Weight	Remarks
						Starting	Running				
AUSTIN CO. NEW YORK 11, N. Y.	Shaft quantizer	Depends on counter	Depends on counter	1 part in 4,000	60/sec				D 1.9 In. L 4.6 In.	2 lb 14 oz	Counter type
THE BALDWIN PIANO CO. ELECTRONICS DIV. CINCINNATI 2, OHIO	16-digit encoder	Reflected binary	16	±0.5 quantum	100/sec	0.5 oz-in.			D 9 In. L 5¾ In.		Flashlamp and photocell readout
	13-digit encoder	Reflected binary	13	±0.5 quantum	100/sec	0.5 oz-in.			D 5¾ In L 6 In.		Flashlamp and photocell readout
	Miniature A2, 5SS13	Reflected binary	13	±0.5 quantum	3,000/sec serial 10,000/sec parallel	0.5 oz-in.	0.1 oz-in.	25 gm-cm²	D 2½ In. L 2¾ In.	1 lb	Steady light source, pulsed photocell readout

COLEMAN ENGINEERING CO., INC. LOS ANGELES 16, CALIF.	P 15 D	Binary	15	±0.5 quantum	Continuous or on demand		Brushes engaged, 0.30 oz-in. Brushes disengaged 0.01 oz-in.	$4x10^3$ in.-oz-sec²	2½x2½x 5½ in.	21 oz	Rotary electromechanical type, dual brush readout
	Digitizer	Decimal	3, 4, 5	±0.5 quantum	Continuous or on demand		0.5 oz-in. 0.01 oz-in.			2 lb 2 oz	Rotary electromechanical type, dual brush readout
	P 10 D-3 C	Binary	10	±0.5 quantum	Continuous or on demand		0.3 oz-in. 0.01 oz-in.	22 gm-cm²	3.56x2½x2½ in.		Rotary electromechanical type, dual brush readout
	P 15 D-4 C	Binary	15	±0.5 quantum	Continuous or on demand		0.3 oz-in. 0.01 oz-in.	22 gm-cm²	5.17x2½x2½ in.		Rotary electromechanical type, dual brush readout
	J 4 D-4 C	Binary-coded decimal	4	±0.5 quantum	Continuous or on demand		0.3 oz-in. 0.01 oz-in.	22 gm-cm²	5.17x2½x2½ in.		Rotary electromechanical type, dual brush readout
DAYTON INSTRUMENTS, INC. DAYTON, OHIO	D1-4-54	Decimal	4, 5, 6	±0.5 quantum	Continuous		0.12 oz-in.		4½x2⁹⁄₁₆x 3¹⁵⁄₃₂ in.	2 lb 4 oz	Mechanical counter with electrical contacts
ELECTRONICS CORP. OF AMERICA CAMBRIDGE, MASS.	309-13	Reflected bin.	13	1 pt in 8,192	600/sec	0.5 oz-in.	0.2 oz-in.		D 4 in. L 6.5 in.	4 lb	Flash tube and photocell readout
	309-13T	Reflected bin.	13	1 pt in 1,024							Sine-cosine, flash and photocell
	309-16T	Reflected bin.	16	1 pt in 8,192							Sine-cosine, flash and photocell
	309-16	Reflected bin.	16	1 pt in 65,536							Linear, flash and photocell
FISCHER & PORTER CO. HATBORO, PA.	Digi-Coder C-2	Binary	14	1 pt in 16,383	8/sec	0.1 oz-in.		$5.4x10^{-3}$ in.-oz-sec²	9⅜x3⅞x4 in.		Mechanical type with coded cams; shaft must be stationary for readout
		Decimal	4	1 pt in 10,000							
GENISCO, INC. LOS ANGELES, CAL.	A 124	Decimal	3	±0.5 quantum	Continuous	0.5 oz-in.			1⅝x1⅝x6¾ in.	2 lb	
G. M. GIANNINI & CO., INC. PASADENA 15, CALIF.	C100	Special binary-coded decimal	3	1 pt in 1,000	2/sec	0.5 oz-in.		423 gm-cm²	4.63x3.9x2.12 in.	1 lb	Mechanical type; shaft must be stationary for readout or damage occurs
JONES & WETTLAUFER ENG. CORP. LOS ANGELES 64, CALIF.	C-4	Decimal	4	1 pt in 1,000		1.5 oz-in.	1.0 oz-in.				
		Decimal	5	1 pt in 10,000							
LIBRASCOPE, INC. GLENDALE 1, CALIF.	707	Binary	7	1 pt in 128		0.4 oz-in.			D 2 in. L 2⁵⁹⁄₆₄ in.	6 oz	Available with diodes for time sharing
	713	Binary	13	1 pt in 8,192		0.4 oz-in.			D 2 in. L 3¹⁹⁄₃₂ in.	8 oz	Available with diodes for time sharing
	717	Binary	17	1 pt in 131,072		0.4 oz-in.			D 2 in. L 4¹³⁄₁₆ in.	11 oz	Available with diodes for time sharing
	719	Binary	19	1 pt in 524,288		0.4 oz-in.			D 2 in. L 4¹³⁄₁₆ in.	11 oz	Available with diodes for time sharing
	723	Binary-coded decimal	4	1 pt in 2,000		0.8 oz-in.			D 3¹⁄₁₆ in. L 4²⁷⁄₃₂ in.	22 oz	Available with diodes for time sharing
	733	Binary-coded decimal	4	1 pt in 3,600		0.8 oz-in.			D 3¹⁄₁₆ in. L 4²⁷⁄₃₂ in.	22 oz	Available with diodes for time sharing
	724	Binary-coded decimal	5	1 pt in 20,000		0.8 oz-in.			D 3¹⁄₁₆ in. L 4²⁷⁄₃₂ in.	22 oz	Available with diodes for time sharing
	734	Binary-coded decimal	5	1 pt in 36,000		0.8 oz-in.			D 3¹⁄₁₆ in. L 6⅜ in.	31 oz	Available with diodes for time sharing
	708	Gray binary	8	1 pt in 256		0.5 oz-in.			D 3¹⁄₁₆ in. L 1¹¹⁄₁₆ in.	8 oz	Available with diodes for time sharing
NORDEN-KETAY CORP. MILFORD, CONN.	ADC-7 BNRY	Binary	7	1 pt in 128		0.2 oz-in.		9.08 gm-cm²	D 1¾ in. L 2¹⁹⁄₃₂ in.	3.7 oz	Parallel readout
	ADC-13 BNRY	Binary	13	1 pt in 8,192		0.2 oz-in.		9.08 gm-cm²	D 1¾ in. L 3¹³⁄₁₆ in.	6.7 oz	Parallel readout
	ADC-19 BNRY	Binary	19	1 pt in 524,288		0.2 oz-in.		9.08 gm-cm²	D 1¾ in. L 5¾ in.	10.2 oz	Parallel readout
STAVID ENGINEERING, INC. PLAINFIELD, N. J.	Mk 2 Mod. 0	Decimal	5	0.01 of 1 speed order 0.36 of 36 speed order	2/sec/ channel						System of encoding nine dual-speed synchro orders
TALLER & COOPER, INC. BROOKLYN 1, N. Y.	Digital converter	Decimal	3	0.1 percent	10/sec	0.5 oz-in.		0.02 in.-oz-sec²	5¼x6⁹⁄₁₆x3⅝ in.	3½ lb	Starwheel readout; shaft must be stationary
WANG LABORATORIES CAMBRIDGE 41, MASS.		Gray binary	10	±1 pt in 1,000		1 oz-in.			4¾x5x2 in.		
W. & L. E. GURLEY TROY, N. Y.		Binary	13	±15 sec of arc					D 2.75 in.	4 oz	Do not make complete converter; only the discs
		Binary	13	±15 sec of arc					D 5.0 in.	7 oz	
		Binary	16	±5 sec of arc					D 10.0 in.	17 oz	

(over for Table II)

TABLE II – VOLTAGE INPUT

Supplier	Model	Range	Number system	Digits	Accuracy	Sampling rate	Size	Weight	Remarks
ASSEMBLY PRODUCTS, INC. CHESTERLAND, OHIO	LIAD		Binary	6	1.5 percent	1 to 4/sec			Conventional electrical meters, revamped with binary scales and readout mechanism. See description in text
ATOMIC INSTRUMENT CO. CAMBRIDGE 39, MASS.	975 Data converter, 570 Data printer	0 to ± 0.25 v	Decimal	3	Short period ± 0.1 percent Long period ± 1.0 percent	1,000/sec	Converter 8¾x19x16 in.		Printing is done by a dot matrix on teledeltos paper
BECKMAN INSTRUMENTS, INC. FULLERTON, CALIF.	Part of 112 Data system	0 ± 10 mv to ± 1 v	Binary-coded decimal	4	± 0.1 percent, ± ½ digit	100/sec			Weighted code 2421 used internally, 8421 externally, transistor and core circuitry
BENSON-LEHNER CORP. LOS ANGELES 64, CALIF.	Model E	0 to ± 10 v 0 to ± 100 v	Decimal	3	± 0.1 percent	3/sec			
BENDIX AVIATION CORP. PACIFIC DIV. NORTH HOLLYWOOD, CALIF.	Meter reader				1 percent	0.3/sec			See description in text
COX & STEVENS AIRCRAFT CORP. MINEOLA, N. Y.	Track scale MP1		Decimal	4		0.3/sec			Self-balancing potentiometer with counter on motor shaft
CONSOLIDATED ELECTRODYNAMICS CORP. PASADENA, CALIF.	Part of Millisadic	0 to 100 v	Binary-coded decimal	3	± 0.2 percent	1,000/sec			Also capable of converting frequency and time
	33-102 Sadic	1 to ± 64 mv	Decimal	3	± 0.1 percent	1/sec			Stepping switch servo type
ELECTRO INSTRUMENTS, INC. SAN DIEGO 10, CALIF.	Digital voltmeters, many models	Common ranges	Decimal	3 to 5	± 1 digit	1 to 2/sec	7x19x16 in. rack mounting	40 lb	Good visual readout
EPSCO, INC. BOSTON 15, MASS.	Datrac B	20 mv (bipolar) to 10,000 v (bipolar)	Binary, binary-coded decimal	11	± 0.05 percent, ± ½ digit	50,000/ sec	19x26x15 in.		
LABORATORY FOR ELECTRONICS, INC. BOSTON 14, MASS.	Digital Multitester	Multi-range	Decimal	3	dc ± 0 5 percent; ac ± 1.2 percent Resolution ± 0.5 percent	20/sec	14¾x9¼x12 in.	35 lb	Essentially a multitester for ac and dc voltages and resistance with digital visual readout
ARTHUR D. LITTLE, INC. CAMBRIDGE, MASS.	Part of Adrad	0 to 20 mv	Decimal	3	0.1 percent	1/sec			
NON-LINEAR SYSTEMS, INC. DEL MAR, CALIF.	Digital voltmeters, many models	Common ranges	Decimal	3 to 5		1/sec	5¼x19x15⅛ in.	40 lb roughly	Good visual readout
RALPH M. PARSONS CO. LOS ANGELES 14, CALIF.	Converter	0 to 10, 0 to 50, 0 to 100 mv	Binary	9		20/sec			Voltage is converted to pulse width and then counting techniques are used
RADIATION, INC. MELBOURNE, FLA.	R-1047-40-1 Coder	0 to 10 v	Binary	8	1 part in 256	24,000/ sec	6 1 3/16 x 9 9/16 x 6¾ in.	8 lb	Especially designed for aircraft use
J. B. REA CO. SANTA MONICA, CALIF.	Rea Converter	30 mv, minimum resolution	Binary, binary-coded decimal and others	13 binary 3 decimal	0.1 percent	8,000/sec to 100,000/sec			Part of Rea data processing system
STREETER-AMET CORP. CHICAGO 13, ILL.	Numerical indicator		Decimal	5		1/sec			Servo with mechanical counter
TELECOMPUTING CORP. BURBANK, CALIF.	Teleducer	Multi-range, maximum sensitivity 10 0v/digit	Decimal	3	0.1 percent	1/sec	21½x15x10½ in.	45 lb	Stepping switch servo



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Controller Options:

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- wide band proportional
- wide band proportional plus automatic reset
- wide band proportional plus automatic reset plus derivative

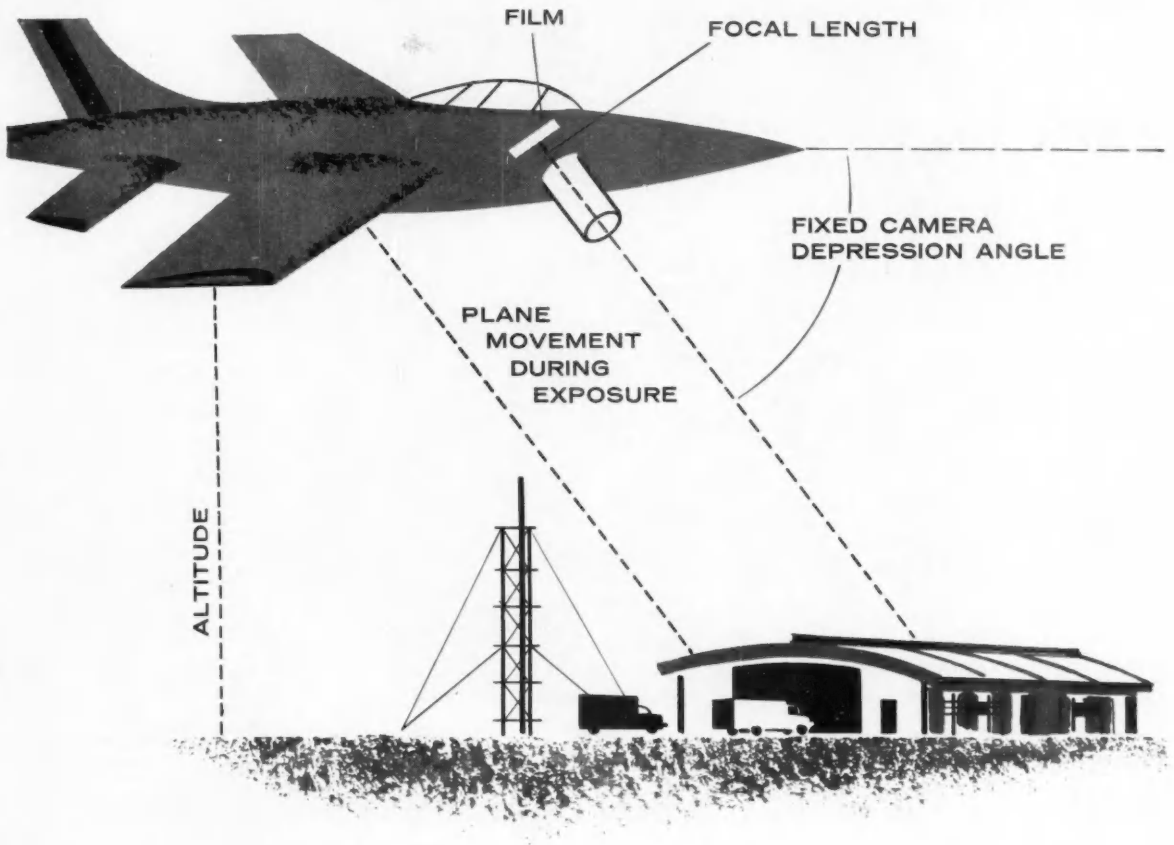
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How Transicoil servos help aerial camera take clear stills even from low fast planes

It's one thing to take a picture of a moving object. But it's quite another to get good clear shots of the ground from low altitude aircraft moving at today's jet speeds. Universal Camera Control System (UCCS) is the latest development in aerial reconnaissance and photography to solve this problem. Designed and engineered by the Bill Jack Scientific Instrument Co., this novel system actually moves the film through the camera to compensate for image movement during the brief exposure time.

Accuracy of the system is dependent on the airborne DC analog computer having absolute dependability and precision under all the environmental conditions of aircraft flight. Extremes of altitude, temperature and vibration cannot impair its effectiveness.

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FM Transmitter Closes Loop from Inside Reactor

Cable deterioration due to neutron bombardment precluded ordinary measurement methods, so an fm transmitter was buried in the reactor with the sample to send out data on changes in the sample due to irradiation. The overall system includes several servos

F. M. GLASS, and
D. O. THOMPSON,
Oak Ridge National Laboratory

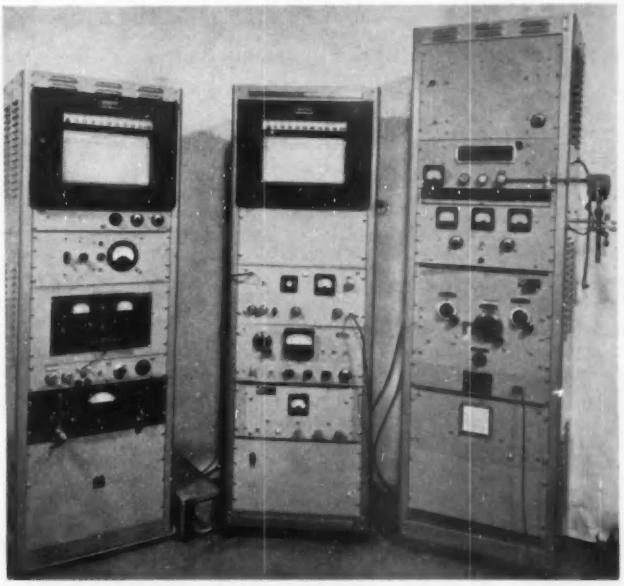


FIG. 1. One strip chart records the change in natural frequency of a metal single crystal due to neutron radiation; the other, the change in energy needed to produce a constant vibration amplitude

Oak Ridge National Laboratory has the problem of measuring changes in Young's modulus and internal friction in metal single crystals due to neutron irradiation. The problem is complicated by the fact that the measurements must be made within a cryostat that is placed inside a reactor in holes 1 to 2 in. in diameter and 25 ft from the operator, at temperatures ranging from 15 deg Absolute to about 100 deg C.

Since Young's modulus and internal friction are intimately connected in many physical processes, it was convenient to set up a system which could measure both. Basically, the resonant frequency of a metal crystal is determined by its length, density, mode of suspension, and Young's modulus. Assuming that the crystal is long compared to its diameter and is suspended at its center, the relation is

$$f = \frac{1}{2l}\sqrt{\frac{E}{\rho}}$$

in which f is the resonant frequency, l the specimen length, E Young's modulus, and ρ the density. The internal friction is a measure of the energy losses within the crystal due to various physical mechanisms, and is defined as

$$\delta = \frac{1}{2\pi}\frac{\Delta U}{U}$$

in which δ is the internal friction, ΔU is the energy dissipated per cycle of vibration, and U is the energy of vibration. This equation is valid for small δ's. There are two ways to measure the internal friction: (1) measuring the amplitude of the crystal's oscillation at constant driving power, or (2) measuring the power needed to keep the crystal driving at constant amplitude. The characteristic curve of the internal friction of pure metal crystals as a function of amplitude is neither flat nor linear, so it was necessary to choose the latter scheme.

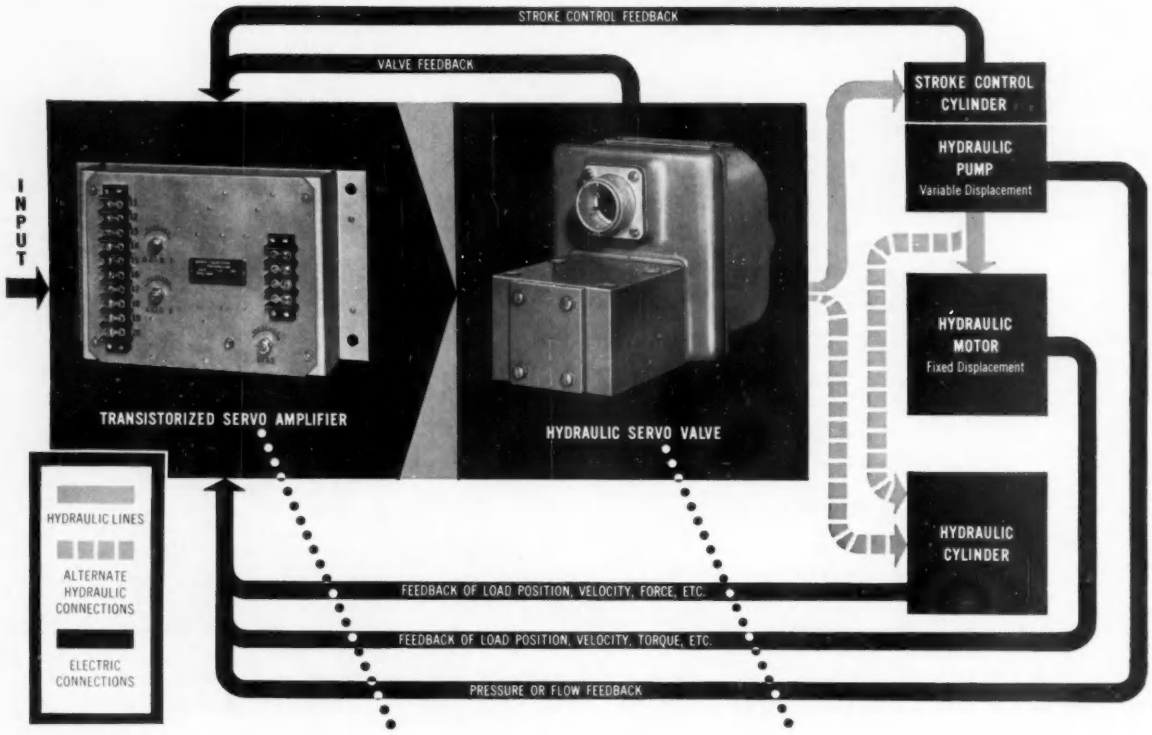
System operation

In this system, the transducer, sample, transmitter, receiver, compressor amplifier, and power amplifier comprise a closed loop. When properly phased, this loop starts and sustains oscillation at the natural vibratory frequency of the sample. The automatic gain-control amplifier compares the output of the receiver with a dc reference voltage and supplies a bias voltage to the compressor amplifier proportional to the error voltage. The gain of the compressor amplifier is therefore automatically controlled to maintain a driving power to the transducer that will produce a constant output at the receiver. Any change in the internal friction is indicated as a driver current change and is recorded on a strip-chart recorder. The resonant frequency of the sample is measured by comparing the signal in the loop with a reference signal. The beat frequency then obtained is measured by a linear count-rate meter and recorded on a second strip-chart recorder, producing a long-period chart of resonant frequency changes of the sample as a function of its environment. The two signals can be viewed on a built-in oscilloscope as a lissajous figure.

The sample under test serves as one plate of the tank condenser in the

announcing *for automatic* machine control

new electro-hydraulic servo team–by Honeywell



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transmitter and thus provides direct frequency modulation. The receiver has sufficient automatic frequency control to compensate for slight frequency shifts caused by temperature deviations and for minor mechanical instabilities in the transmitter.

The fm transmitter has been operated continuously in a fast neutron flux of about 7 x 10^{13} neutrons/cm^2/sec, while being temperature-cycled between minus 253 and 90 deg C for several weeks with no adverse effects.

The equipment as designed will record slowly changing characteristics of the metal sample, as a function of environment, over long periods of time without attention.

Design considerations

Control requirements for the apparatus are rigid, dictating rigid design specifications. For example, the amplitude of vibration in the crystal under test must be controlled to within 1 percent regardless of changes in the modulus of elasticity. This means that all the amplifiers in the self-excited loop must have flat frequency response of plus or minus 1 db between 5 and 100 kc. It also means that the agc amplifier and the fm receiver must have excellent gain stability. The agc amplifier should have a gain of not less than 2,000 to maintain a very low error signal at the input of the compressor amplifier. The response of the agc amplifier to 60 and 120 cycles must be down at least 80 db to prevent modulating the loop signal in the reference comparison circuit.

As in the case of all closed-loop control systems, certain precautions are necessary here to prevent over-shooting and hunting. This problem is magnified in this system by the gain of the agc amplifier, since it comprises another closed loop within the loop. The hunting problem was solved by using a filter time constant much shorter than the equivalent mechanical time constant of the crystal, plus full-wave rectification of the bias control voltage. Crystal mounting prevents its responding to the second-harmonic ripple from the rectifier.

The extreme temperature cycling of the metal crystal and fm transmitter cause carrier-frequency drift, obviated by servo-tuning the receiver.

The fm radio link eliminates the problem of balancing out any radiation damage to the insulated cables which would have to be used with a more conventional bridge circuit. The good signal-to-noise ratio of fm is also needed, since the amplitude of linear displacement in the crystal is controlled within the limits of 3 x 10^{-7} to 4 x 10^{-7} in.

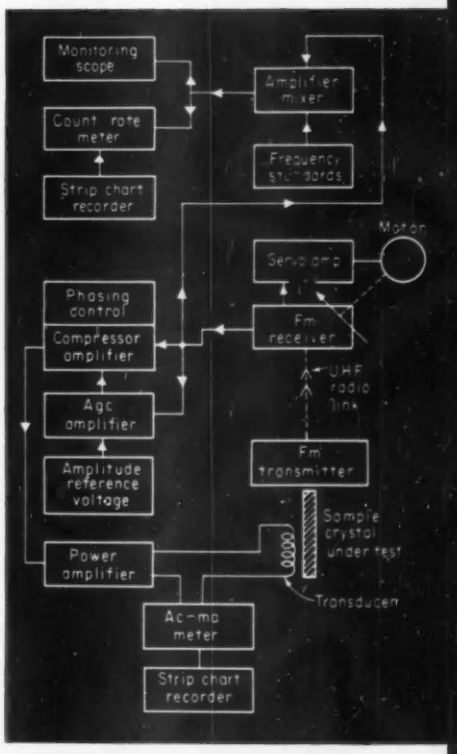


FIG. 2. Loop is closed through fm transmitter placed in reactor with metal sample. Receiver is servo-tuned to obviate drift.

Optimize Combustion Control on Open-Hearth Furnaces

Ordinary fuel-air ratio control systems can be improved by controlling combustion air according to the percent unburned oxygen among the waste gases. Here's a system that uses this quality measurement to bias the fuel/air controller.

F. S. SWANEY
Jones & Laughlin Steel Corp.

One way to establish and control combustion conditions in open-hearth steel furnaces is to properly proportion combustion air for the amount of fuel being fired. Such control is termed fuel-air ratio control and is generally installed on any fuel-consuming unit of appreciable size in a steel plant. The variable here consists of volumetric flow measurements on both the fuel and air flows, which are subject to errors due to metering inaccuracies. These errors are reflected directly in changed combustion conditions.

Open-hearth furnaces are reversed every few minutes by blowing the combustion air through a passage that immediately before had served as a flue, thus preheating the air. Air infiltration can vary from end to end, and cannot be controlled. Also, at certain stages of the heat, gases evolving from the bath enter into the combustion reaction taking place. Since the rate of gas evolution can and does vary widely during different stages of the heat, and from heat to heat, compensation for this variable is extremely difficult to apply. Thus the furnace operator usually resets the ratio setting at different stages of the heat to compensate for the chemical reactions taking place. The extent and duration of these adjustments are, however, solely a matter of judgment and may be considerably in error.

There is an increasing trend in the chemical and petroleum industries toward "end-point control". For example, say it is desired to mix fluid *A* with fluid *B* to produce product *C*. Since a definite ratio exists between the number of units of *A* and the number of units of *B* which will produce an optimum yield of product *C*, the ratio of *A* over *B* is normally maintained constant with a ratio controller. Such a control system is subject, of course, to the metering errors mentioned previously. However, if it is



Contact points able to survive this brutal shear test stay on forever

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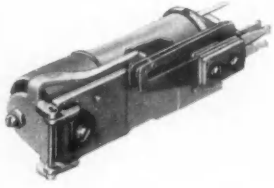
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GENERAL SYSTEM

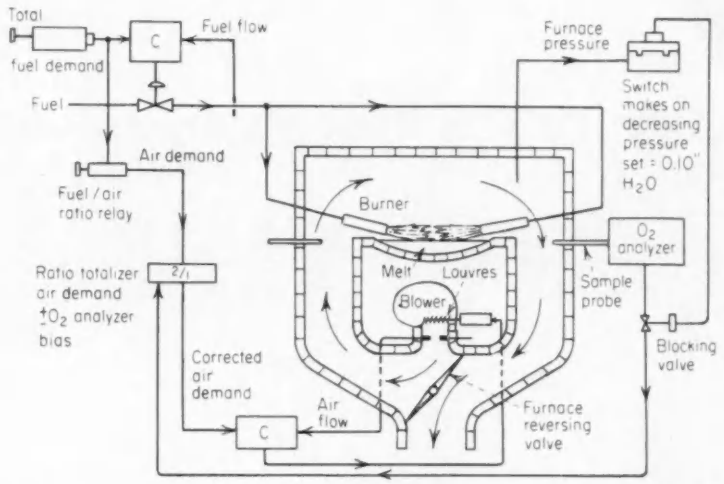


FIG. 1. Open hearth furnace, with schematic of O_2 analyzer combustion control system.

possible to measure directly some property of the product C which bears a direct relationship to the mixture ratio of A and B, then it is possible to continuously control either A or B so as to maintain the desired mixture ratio for best yield and quality product*. This eliminates all possible discrepancies in the measurement of the flowing fluids by by-passing them and controlling directly from the end-product.

Since optimum combustion conditions are indicated by a certain waste-gas analysis, the direct, or end-point, method of controlling this process would be to control the ratio of fuel to air from waste-gas analysis. Two constituents in the waste gas, CO_2 and O_2, are indicative of combustion efficiency. Control from CO_2 analysis has two serious disadvantages: (1) the percent CO_2 present in a waste-gas analysis varies with the type of fuel used and therefore is useless on multi-fuel-fired heating units; (2) maximum combustion efficiency is indicated by maximum percent CO_2, requiring a peak-finding controller. Control from O_2, fortunately, has none of these disadvantages.

* "Improved Ratio Control with Composition Analyzer", Control Engineering, January 1957, page 113.

System description

The oxygen analyzer is of the paramagnetic type and obtains its waste-gas sample by means of special water-cooled probes (CtE, April 1956, p. 105) in each downtake of the furnace a few feet above the floor in the port-end wall. The gas sample is aspirated through the center of the probe by means of a steam ejector. With this type of installation, there has been very little trouble keeping the probes clean for extended periods.

After the analyzer had been in operation as a recorder long enough to demonstrate its reliability, it was decided to add the control function. Before this could be done, however, it was necessary to ascertain which furnace conditions or operations would so interfere with the oxygen analyzer operation that their signal would be useless as a source of control. A careful test of furnace operation, during which all variables except one were maintained constant, revealed that the only one with an appreciable effect on the oxygen analysis was furnace pressure. Accordingly, the system was so designed that the control would be locked out during periods in which pressure was less than 0.10 in. of water.

Figure 1 is a simplified diagram of an open-hearth furnace with an oxygen analyzer fuel-air optimizing system. The control system itself is pneumatic, with proportional-band and automatic-reset adjustments, and operates so as to bias the simple fuel-air ratio system. Thus, the oxygen analyzer is used as a trimmer on the ordinary combustion-control system.

Operation

Figure 2 shows typical chart records obtained on the furnace while the oxygen analyzer was recording only. The chart on the left is percent O_2 in the waste gases and the chart range is 0 to 10 percent O_2. The chart on the right is a record of the total fuel and total air flow to the furnace. The higher of the two records, in all cases, is the total fuel flow. As can be seen from this chart, the furnace was operating under automatic fuel-air ratio control. Still, the O_2 analysis varied from 0.3 to 7.0 percent O_2.

Figure 3 shows the same two chart records under oxygen analyzer control. The O_2 record shown indicates the waste-gas analysis was kept within much narrower limits and normally did not vary more than 0.5 percent on either side of the set-point of 2.0 percent. The large variations were due to control lock-out because the furnace pressure was low or because no fuel was being fired. In both Figure 2 and 3, midnight is at the right side of the smaller (O_2) chart, and time progresses counter-clockwise. Midnight is at the top of the fuel- and air-flow chart, and time progresses clockwise. Both show 24 hours. Since furnace pressure is not indicated, O_2 variations from this cause cannot be checked on these charts.

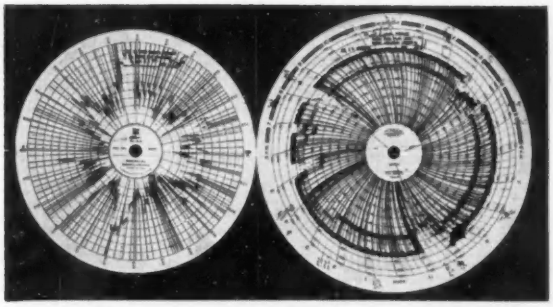


FIG. 2. Oxygen analyzer recording, left, compared to total air flow to furnace, right, for fuel/air ratio control only.

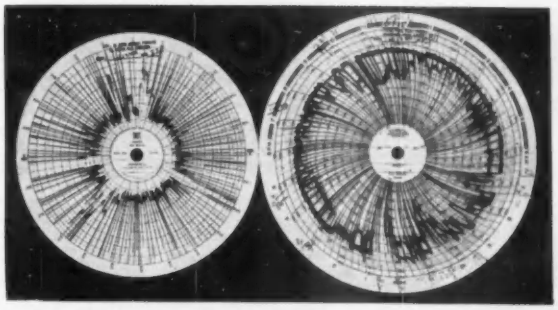


FIG. 3. Chart records of Figure 2 under oxygen analyzer control. Note consequent variation in total air flow.

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Freight-Car Classifier Is Plugboard-Programmed

The Swedish State Railways' classification yard at Ange can distribute cars automatically to any of 24 tracks. Track destinations for each car are recalled from plugboard memory as necessary.

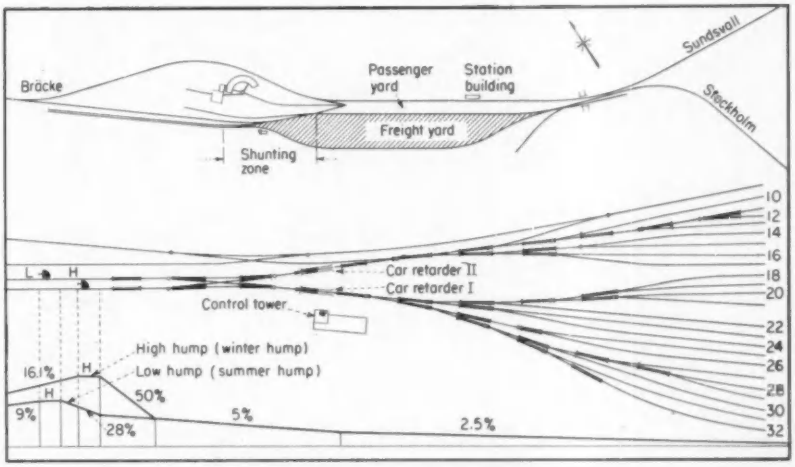


FIG. A. Plan and profile views of Ange freight classification yard. At the side of the shunting zone is a control tower from which switches and retarders are operated. An incoming freight train is slowly pushed over one of the humps, where a "cut" of one or more cars is detached to roll by gravity to a selected track on which a train is being made up for a new destination.



FIG. B. The Ange yard is at the 62nd parallel, and has severe winters. Car retarders and switch points are electrically heated to assure reliable operation in spite of snow and ice. Retarders are hydraulic (of German manufacture; American makes are commonly pneumatic) and automatically regulate retarding pressure according to weight of car.

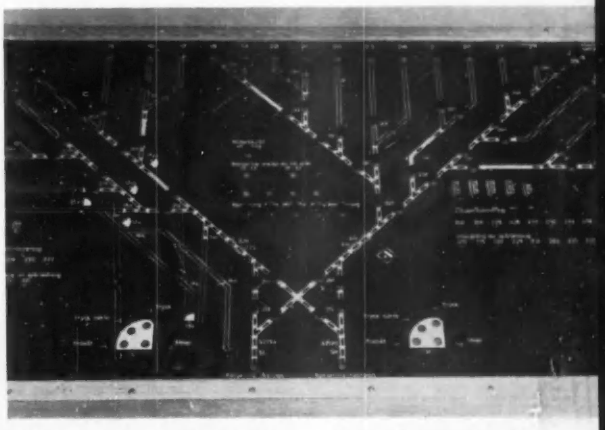


FIG. C. The track diagram represents the track system in the shunting zone. It has pushbuttons for each of the individual switching points. There are toggles for local operation of points, and pushbuttons for signal operation and communication with the interlocking plant in the passenger yard. Lamps show the state of points, track circuits, etc.

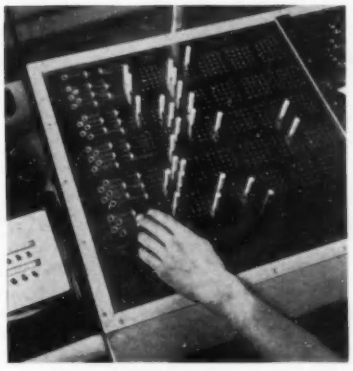


FIG. D. The shunting program operating panel is a plugboard. Each vertical row of holes corresponds to a cut of cars, and each horizontal row to a track in the yard. One plug for each cut is placed in the hole marking the position of the cut in the train and its destination track. Photocells determine that "cut" has passed a switchpoint (switchover: 0.5 sec).



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Three Genisco Accelerometers help the Super Sabre close in

If enemy air infiltration happens, you can be sure that modern knights of the sky powering the swift *Super Sabre* at speeds faster than sound will spearhead America's defense.

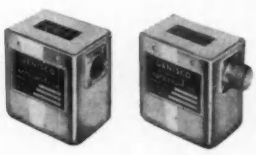
Typical of today's supersonic aeronautics, the USAF's *Super Sabre* reflects the finest contemporary engineering skill and scientific creative imagination. But this swept-wing assassin is more than just another jet-powered plane. It is a proven, integrated electro-mechanical system, combining a multitude of precision sub-systems, assemblies, and individual parts.

The automatic flight control system, for example, consists of numerous components, each one vital to the performance of the system. Naturally, component reliability is imperative if the plane is to carry out its mission. The flight control system of the F100D incorporates three Genisco Model DDL Accelerometers.

The Model DDL is only one of many Genisco Accelerometers now in use on America's air guardians, including our most important operational guided missiles. Like other models, the DDL was designed for a particular application—to function perfectly in the severe vibrational and shock environment of supersonic flight.

Genisco's ability to design for the most stringent applications and to produce precision instruments in large quantities has made the company an important link in our nation's defense chain.

Descriptive technical data on the Model DDL and other Genisco accelerometers will be sent upon request.



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Dead Time Simulated by Transport Delay

This pneumatic-mechanical device uses the cause of dead time, transport delay, to produce a near-ideal simulation for delays longer than 5 sec. Output is a pneumatic signal in the 3-15 psi range.

P. E. A. COWLEY, and
A. BREMER,
Shell Development Co.

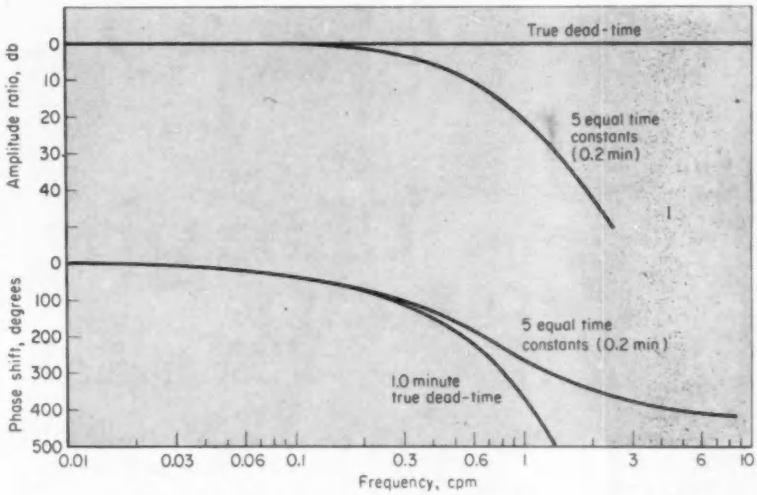


FIG. 1. Comparison of true dead time with a 5-time constant approximation.

Dead time, or transportation delay, encountered in nearly every commercial process and in most control systems, can be adequately approximated or truly simulated on a new analog device, which produces dead time by a method truly analogous to the manner in which it is produced in plant operation; that is, by transportation delay.

Dynamic analyses of plant processes and their associated control systems have proven very useful for solving plant operation problems or for specifying the best control system for a plant in the design stage. The linearized dynamic behavior of a process can nearly always be expressed by three terms: gain, time constants, and dead time. If real values for these characteristics can be determined by test, calculation, or even accurate assumptions, an analog study can be made of the problems involved. Gain and time constants can be simulated easily, but true dead time simulation is more difficult because in the frequency domain it has a phase shift proportional to frequency, but a constant unity amplitude ratio.

Where the dead time is small compared with the major time constants, it may be neglected; where it is too large to be neglected but considerably less than the major time constants, it may be approximated in the analog; and where it is comparable with or even greater than the major time constants, it must be truly simulated on the analog because it plays a major role in the quality of control that can be achieved by instrumentation. Every process that has material moving from one point to another has some dead time due to transportation delay, and when continuous analytical instruments are used for control there is often a dead time in the sampling system which approaches or is greater than the major process time constant unless the analysis is performed in the process stream directly.

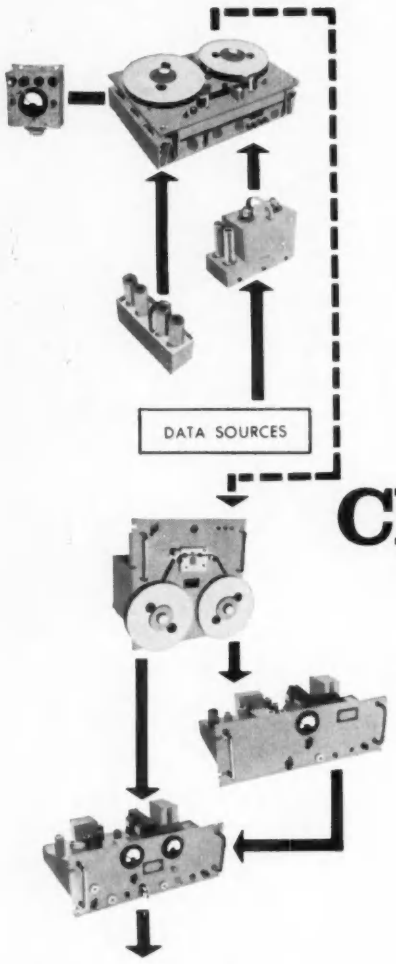
The most common method for simulating dead time is approximation. One approximation technique is to use many time constants in series. Quite often this system contributes some attenuation and insufficient phase shift at critical response frequencies. A comparison of true dead time and the response of five series-connected equal time constants is shown in Figure 1 to illustrate this. Network approximations used in electronic analog computers are often unsatisfactory for similar reasons. Furthermore, the network approximation often consumes too many computing components, so that other process characteristics cannot be simulated with the required accuracy.

One electrical unit on the market which could be adapted for use as a true dead time device is the Pratt & Whitney Proportional Synchronizer. It has a fairly slow input response, however, and short dead time could not be simulated with good accuracy.

The dead time device

To exactly simulate in the laboratory any reasonable amount of dead time that might be encountered in processes, the following requirements for the device were set forth:

- An operating principle based on transportation delay—the cause of dead time.
- Pneumatic input and output signals so that it can be used with pneumatic analogs directly, or with electrical analogs by using suitable input and output transducers. The signal range should be adjustable within practical limits, such as a 5-psig span between 3 and 15 psig.
- A continuously adjustable range of dead times between practical limits, such as 5 sec to 10 min.
- No change in amount of dead time with input frequency or amplitude.
- An over-all gain preferably of 1.0;



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Choosing A System

for magnetic tape DATA recording

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To take advantage of the broad range of equipment and techniques now available, start with a thoroughgoing analysis of your own present *and future* data handling . . . data processing needs. Then, match the techniques and individual components *to those needs.*

Choose the recording method first: Direct recording is limited in data work by its poor amplitude reproduction and poor low frequency response on playback. Pulse width modulation (PWM) recording is excellent for recording a large number of channels with limited frequency response. Digital recording offers extremely high data accuracy, but relatively low information capacity.

FM recording, electronically compensated for wow and flutter, offers a combination of high overall system performance, frequency response, and information capacity, suiting it for most analog recording applications. Any or all of these methods can be supplied in the same recording system by inserting the proper plug-in circuitry.

Consider physical requirements next: Where you plan to use a system is an extremely important factor. To record data in a missile or jet, you will obviously need different equipment than would be used in a laboratory. But reel size, tape width, tape speeds, must also be selected. And heads, available for recording from 2 to 24 data tracks or even more, should be specified early. Keep in mind also the planned final disposition of the data, whether to a computer, direct writing recorder, or other equipment.

Finally, select system components and accessories: In FM carrier recording alone, you can choose from at least three recording oscillators, two reference generators, and several signal and compensation discriminators. Speed control servos, power supplies, and remote controls also require attention.

Needless to say, much of this process of selection requires special experience, and should be placed in the hands of the competent data recording systems manufacturer. But the important thing to remember is that data recording on tape is a field in itself, with special techniques and special equipment that can be matched to virtually any recording need. The day when the problem had to be tailored to the equipment is long past.

More detailed information on recording systems and equipment, and how to select them, is provided in "The Role of Magnetic Tape In Data Recording," available on request to Davies Laboratories, Div.

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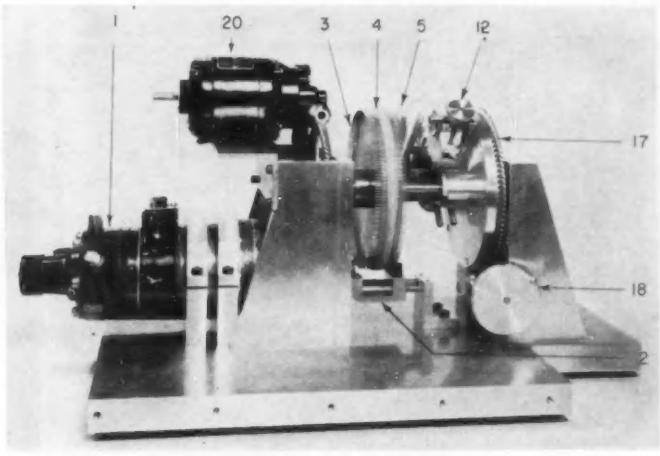


FIG. 2. Functional view of dead-time unit.

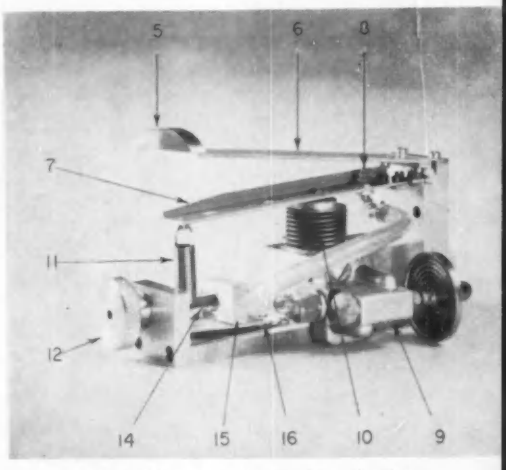


FIG. 3. Output device used on simulator.

in any case, the gain must be known exactly.

The general construction and operation of the simulator is illustrated by Figures 2 and 3. It is essentially mechanical with mechanical-pneumatic input and output devices. The input device (1) is a ¼-in. valve topworks with integral valve positioner. The valve stem positions the sliding "V" block (2) and hence the pins (3) in the memory wheel (4), which revolves at constant speed. After some delay, which is the actual dead time, the pins arrive at the output device which transmits an output air pressure proportional to the position of the pins.

In the output device the sensing head (5), which is carried by the flapper arm (6), is lightly spring-loaded against the pins. Motion of this sensing head changes the baffle-nozzle relationship, hence the output pressure from pilot relay (9) and the feedback pressure in bellows (10). The output pressure span is determined by spring (11), and mean pressure may be varied by knob (12) which moves the leaf spring (16).

The output device is carried by the worm wheel (17), which is mounted on a bearing concentric with the axis of the memory wheel. The angular distance (and hence the dead time) between the input and output devices may be adjusted by means of the hand wheel (18). The memory wheel is driven at approximately 1 rpm by the universal motor (20). The motor is supplied with line current from a variable transformer which enables the speed to be reduced and the dead time increased by about a factor of 10. The combination of motor-speed adjustment and angular-distance variation between input and output devices allows a range of dead times continuously adjustable between 5 sec and 10 min.

The completed simulator is shown in Figure 4. A reducing relay and a reversing relay with biasing springs are mounted behind the front panel with input and output ports terminating at quick-connect fittings on the panel. This feature provides great flexibility, since the relays may be "patched in" before or after the dead time unit. Full mechanical travel of the pins is ¼ in., and is obtained with a pneumatic input signal of 6.5 to 11.5 psig. This signal range is ideal when the unit is used with an analog computer to study small signal disturbances in control loops. When large disturbances are to be studied, the reducing relay may be "patched in" ahead of the dead-time unit. The output air pressure ranges from 3 to 15 psig for full mechanical travel of the pins.

Simulator performance

The minimum amount of dead time which the device can simulate is de-

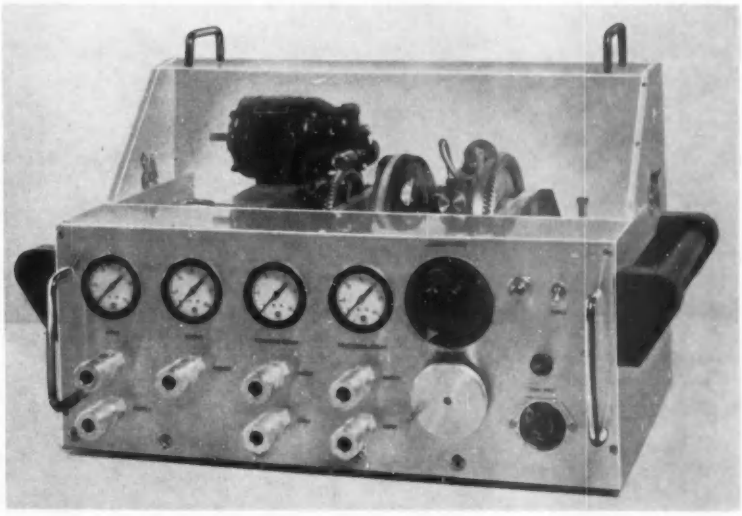
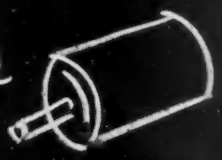


FIG. 4. Dead-time simulator has quick-disconnect pneumatic fittings for convenience.

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termined by the response speed of the input device and the minimum angular distance between the "V" block and the sensing head. The miniature valve topworks with its positioner can follow frequencies of 0.5 cycle per second with little attenuation or phase shift. The minimum dead time is limited to 5 sec, which is 15 times slower than the time constant of the input device, to prevent excessive errors due to input-response speed limitations. The minimum time required for the memory wheel to travel the shortest distance between input and output is about 3-sec.

The maximum amount of dead time is limited only by the speed of the motor which drives the memory wheel. Though this motor can be selected so that dead times of an hour or more can be obtained, 10 min was chosen as a practical limit.

It is of interest to compare the performances of this unit with the performance of an active network used on an electronic analog computer for simulating dead time. Taking as a "figure of merit" the ratio of dead time to rise time (80 percent of final value), the values are:

Type of dead time unit	Figure of merit
Active network (4 integrators)	2.8
Mechanical-pneumatic	100.0

The extremely good "figure of merit" of the mechanical-pneumatic device is due to the large information storage of the memory wheel. If the memory wheel is not fully used (during dead times of less than 1 min, for example), the "figure of merit" is reduced accordingly. For a dead time of 10 sec the value is 17, which is adequate for most purposes.

The step-function response with a 36-sec dead time is shown in Figure 5. The output is reversed in this illustration, but "rises" rapidly to give an effective "figure of merit" of about 70. There is some "noise" in the output due to slightly unequal pin lengths.

Because a finite number of pins is used in the memory wheel, the information that is stored is a sampled version of the input. The output consists of this sampled version of the input delayed and smoothed by the shape of the sensing head. In Figure 6 the sine-wave response shows a small amount of sampling "noise". The larger the radius of the sensing head, the smaller the sampling noise but the larger the wave-form distortion. Large distortions occur only when the radius of curvature of the signal stored in the memory wheel becomes comparable with the radius of curvature of the sensing head. It follows then that distortion is also a function of the amplitude of the signal stored in the memory. The shape of the sensing head is thus a compromise between sampling "noise" and waveform distortion at high frequencies. As the shape of the sensing head approaches a triangle and as the point of the triangle moves from pin to pin, the output signal appears as a series of stair steps.

Future developments

The simulator, which meets all of the requirements listed above, has been used on numerous problems to simulate actual process dead times. Certain improvements have been considered for extending its use to: (1) a function generator (by disengaging the input device after the function is stored in the memory wheel); provide multiple output signals with various delays (by adding more sensing heads and pilot relays to the output device); and simulate the variable dead time encountered when pump speeds vary (by servo-control of the driving motor). These additional applications would make an even more valuable instrument out of one that has proven to be essential to accurate control-system analyses.

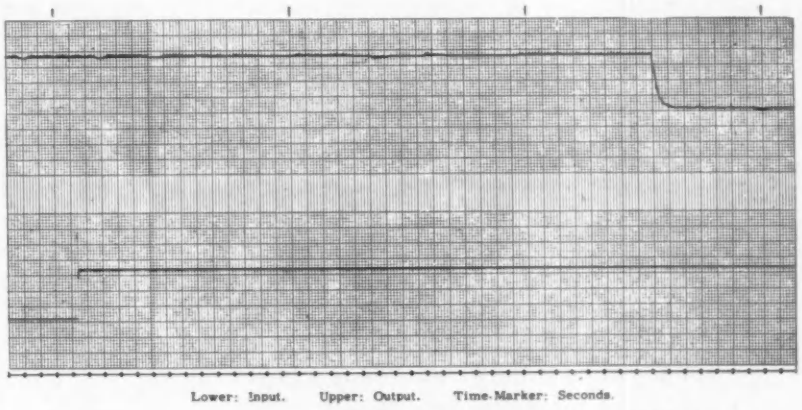


FIG. 5. Step-function response to 36-sec delay.

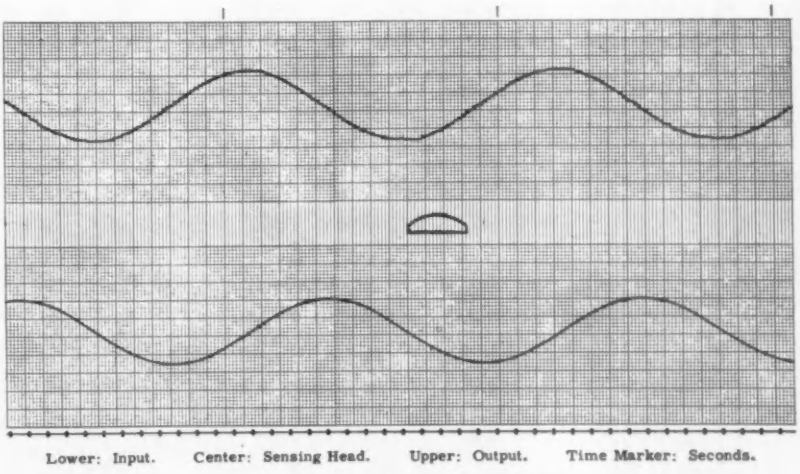


FIG. 6. Sinusoidal response at 3½ cpm shows sampling noise.

A Progress Report on Faculty Salaries:

UP...But Not Nearly Enough

THE CHART on this page provides a report of the progress being made in solving a problem of crucial importance to every American. The problem is that of seeing that college and university faculty members get decent salaries.

This new chapter, which brings the story forward two years—from 1954, when it was last dealt with in this series of editorials, through 1956—has a decidedly cheering element. For in the last two years faculty salaries have made real headway.

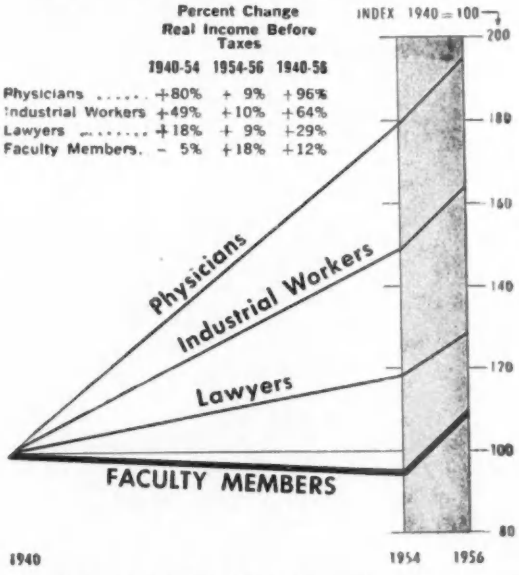
Two Years of Improvement

In 1954, in terms of what their salaries would buy, faculty members as a whole were actually worse off, by 5%, than they had been fourteen years earlier. As the chart shows, over the same period the real income of the average industrial worker had increased by almost half. And, in what it would buy, the income of the average physician, with professional training comparable to that of the average faculty member, had jumped by 80%.

In 1956, however, the average faculty salary would buy about 12% more of goods and services than it would in 1940. Relative to where they were two years before, faculty salaries showed a larger gain over the two years than those of any of the other groups whose salary progress is charted.

This movement of faculty salaries in the right direction has many contributing causes. The biggest single boost was given by the great Ford Foundation gift of half a billion dollars to our colleges, universities, and hospitals, almost half of which was ear-marked for faculty salary increases. Gifts from business firms have also

What is Happening to College Faculty Salaries



DATA: Council for Financial Aid to Education, U. S. Dept. of Commerce, U. S. Dept. of Labor, National Association of Education Research Dept., McGraw-Hill Dept. of Economics.

helped a lot. And so, in many cases, have stepped-up money-raising campaigns by alumni groups and cooperative regional and state groups of colleges.

Still a Long Way to Go

However, faculty salaries started their ascent from such a dismal depth that they still have a long, long way to go up before there is room for the comfortable conviction that they are fair, or even safe, from the standpoint of protecting the nation's vital interests. It still remains possible to find many shocking companion pieces for the following incident recently reported to a McGraw-Hill executive group, working on problems of financial aid to higher education, by the president of an illustrious small liberal arts college.

"The recruiting officer of one of our large industrial companies came to our campus a few weeks ago," the college president said, "and offered five of our seniors higher salaries to start working for that company when they are graduated next June than the salary received by any member of our faculty. And the seniors, of course, promptly went to their professors to seek advice on whether or not they should accept. It doesn't take much imagination to see what this sort of thing does to the morale of a faculty."

Senior Teachers Fare Badly

One of the more devastating things it does, of course, is to make the more experienced college and university faculty members receptive to the idea of going to greener pastures, currency-wise, in business and industry.

For these senior faculty members the financial pounding in the past 16 years has been even worse than the chart indicates. While the average real salary gain reported by the chart has been 12%, the average salary of a full professor still buys less than it did in 1940. This is because most of the salary increases have gone to beginning instructors, for whose services industry has been providing the sort of competition reported by the liberal arts college president.

And it creates this financial lackluster of posts as senior college faculty members right at the time their services are needed more than ever to handle the oncoming flood of college and university students. Between now and 1970 college and university enrollment is expected to double.

What is Needed Now

What is clearly needed is a continuation and intensification of the drive to increase their salaries to a point where college and university faculty members will be sharing somewhere near fully in the general prosperity of the nation. It could be counted good progress in this direction if over the next two years faculty salaries on the average were to go up another 12%, with most of the increase concentrated in the senior faculty ranks. And this can be made possible only through more outside contributions.

There is reason to be encouraged by the progress that has been made over the past two years in bailing college and university faculty members out of the terrible financial hole into which they were allowed to slide. But there is the most urgent occasion to keep at it and harder.

This message is one of a series prepared by the McGraw-Hill Department of Economics to help increase public knowledge and understanding of important nationwide developments that are of particular concern to the business and professional community served by our industrial and technical publications.

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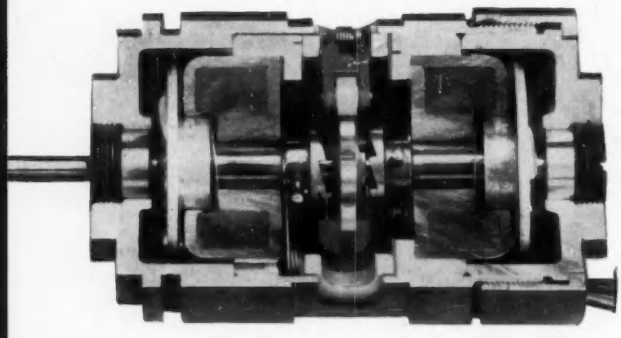
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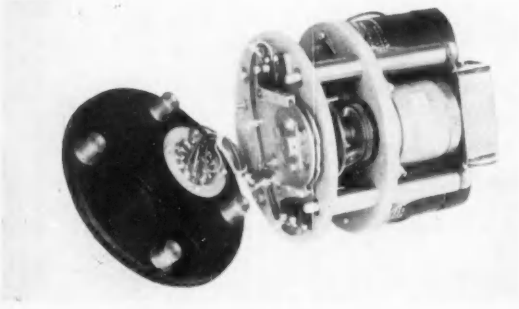
NEW PRODUCTS

LISTING IN GROUPS

1-5 Designs of the Month
6-10 Research & Development
11-13 Machine Tool Control
14-21 Measurement & Data Transmission
22-24 Information Display Instruments
25-29 Control Devices
30-32 Power Supplies
33-37 Final Control Elements
38-46 Component Parts
47-48 Accessories & Materials







REVERSIBLE STEPPER MOTOR uses rotary solenoids, yields high-speed accuracy.

Developed at Northrop Aircraft, Inc., and licensed to the Stepper Motors Corp. for manufacture and sales, this new stepping motor (cutaway view) uses two rotary solenoids to produce incremental motion of its output shaft in either direction. Energizing either of these solenoids produces a combination of linear and rotational motion which moves a ratchet axially into engagement with a mating ratchet and thus imparts a given amount of rotation to the output shaft. The shaft, detented to the motor case, has equal detent action in either direction. Each revolution consists of ten 36-deg steps. The solenoid drives the shaft 35 deg during each pulse. The rear faces of the driving ratchet engage like surfaces on the driven ratchet to prevent the load from overriding the detent mechanism. A roller-spring detent assembly maintains the output-shaft position while the motor is at rest with the power off. While characteristics vary with the application, the Model SM300-1 has a maximum pulse or stepping rate of 15 per sec, a maximum pulse time of 56 percent, and a temperature range of minus 65 to plus 165 deg F. The motor operates on 28 vdc, drawing 800 ma at room temperature. Reliability is extremely high. The manufacturer claims a maximum error of one step in a million. Under test by the Wyle Research Corp., a production model underwent a million cycles in each direction without failing to convert a single pulse.

Center and bottom photos, left, show an automatic pulse timer and a synchro positioner, both of which incorporate these motors in their design. The former will time from two to 60 pulses with an accuracy within 0.01 sec. Its components include a spring-powered stop-watch that is easily removed for winding, the stepping motor, two solenoids, an annular indicator dial, and suitable switches and gearing. In operation, the watch is wound and set in place, the indicator dial set at the desired number of pulses, and the operating knob pushed in. The stepping motor drives an index cam which, after the desired number of pulses has been counted, cuts off all power. Time required is indicated on the stop-watch.

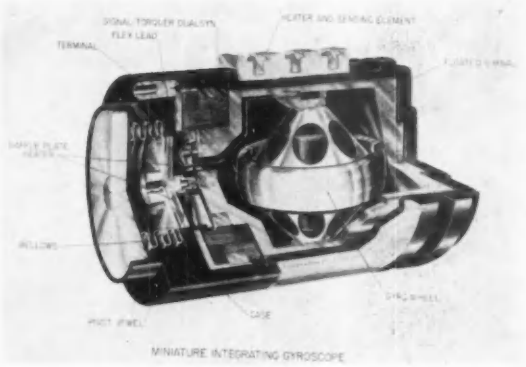
The synchro positioner uses two stepping motors, a Bendix Autosyn differential, and a built-in pulse-generator. One motor positions the Autosyn shaft in coarse increments in either direction, while the other, using a different gear ratio, positions the same shaft in vernier increments in either direction. As the reset command signal is of steady-state type, the built-in pulse-generator permits use of the driving motors for the reset function. Accuracy is within 6 min of arc when driven by either motor.—Stepper Motors Corp., Culver City, Calif.

Circle No. 1 on reply card

"FLOATED" GYRO weighs only 8 oz.

Shown is a miniaturized "floated" gyroscope that weighs 0.48 lb and still meets the low-drift-rate requirements of short-time automatic guidance systems. The signal and torque generators have been combined into a single dual-microsyn, designated as the Dualsyn, and placed at one end of the case with the gimbal at the other. Both are enclosed in a single aluminum case. The gimbal suspension pivot has been reduced to 0.016 in. in diam, and a new method of fluid-fill virtually eliminates balance-shifting air bubbles. A new isoelastic spinmotor and mounting structure improve performance under vibration. Gimbal travel is held to within 3 deg of null.—Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

Circle No. 2 on reply card

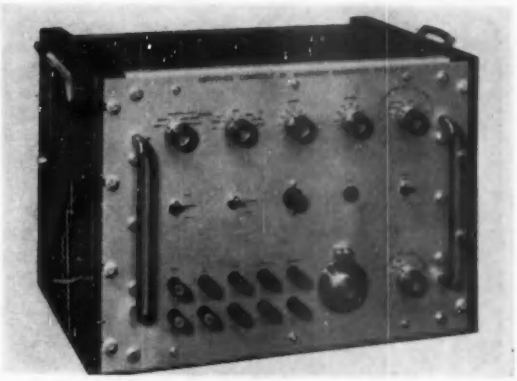


MINIATURE INTEGRATING GYROSCOPE

WAVEFORM GENERATOR tests systems.

This low-frequency waveform generator, called type IF.51, generates a wide variety of electrical test signals over the range of frequencies encountered in servomechanisms, process controllers, and mechanical systems in general. The unit also has applications in programming and analog computation. It generates sine waves from 500 down to 0.0005 cps (one cycle every 33 min), and square waves and pulses with durations of 100 microsec up to 1,000 sec. Ramp functions, triangular, sawtooth, trapezoidal, and cosine-shaped pulses can also be generated. A plug-in nonlinear shaping unit can be modified to simulate almost any desired function—Servomex Controls, Ltd., Sussex, England.

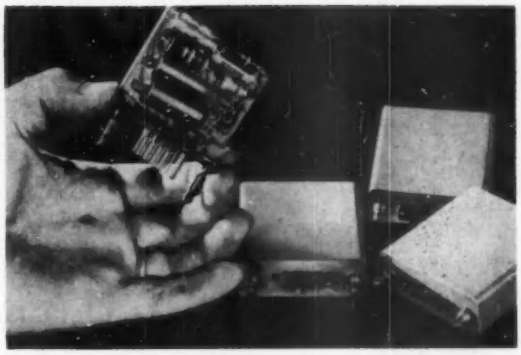
Circle No. 3 on reply card



STANDARDIZED PANEL improves PC design.

Printed-circuit-design theories have been applied by Westinghouse to molded units for aircraft equipment. Previous designs packed the components so as to utilize the volume to best advantage, with little regard for circuit arrangement. A newly designed standardized panel permits a neater circuit arrangement without sacrificing the other advantages. This panel uses a $\frac{1}{10}$-in. grid system. Conductor paths are etched on it and holes for connecting leads are punched from a universal template. This permits prebending of component leads.—Westinghouse Electric Corp., Pittsburgh, Pa.

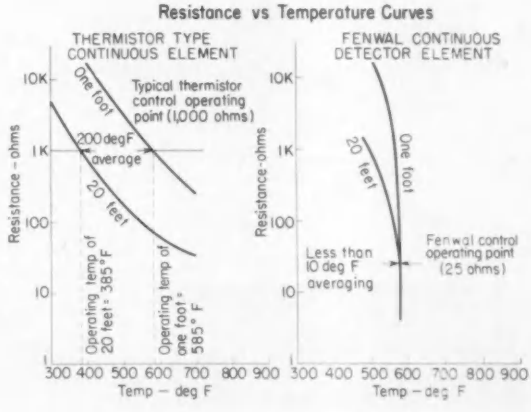
Circle No. 4 on reply card



NEW SYSTEM solves averaging problem.

In the past, fire and overheat detection systems have used thermistor-type sensing elements. The operating point for such systems is around 1,000 ohms, i.e., the control unit is actuated when the resistance of the element drops to 1,000 ohms. However, there is a wide divergence in temperatures required to reach this point when the lengths of the sensing elements are different. This is known as averaging. Now, by means of a magnetic amplifier, a brand new sensing element incorporating inorganic salts, and an operating point of 25 ohms, Fenwal has beaten this problem. Both widespread overheat conditions and localized flames will actuate the control unit within 10 deg of each other. Graphs at the right indicate this improvement.—Fenwal, Inc., Ashland, Mass.

Circle No. 5 on reply card



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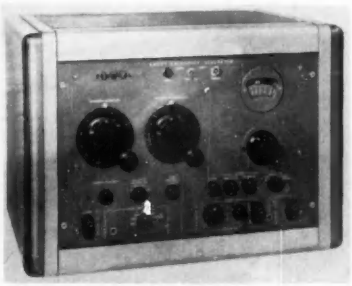
NEW PRODUCTS

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Circle No. 6 on reply card



COMPONENT TESTER

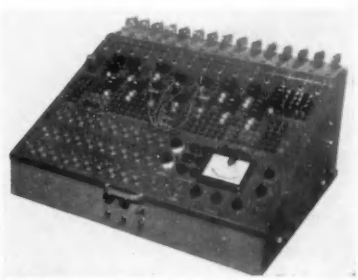
A new swept-frequency generator, Model 200 K, simplifies accurate and rapid production testing of a variety of electronic components. It provides instantaneous and continuous amplitude-vs.-frequency displays of high accuracy when used with a large-screen oscilloscope, and permits the operator to instantly determine the effects of changes in circuit values upon frequency characteristics. The unit has an output frequency range of 20 cps to 200 kc and a frequency deviation range of 0 cps to 200 kc. For full deviation, sweep linearity is within plus or minus 2 percent. A patented variable marker circuit places a marker pulse on the oscilloscope display at any frequency within the range of the instrument.—Federal Telephone & Radio Co., Clifton, N. J.

Circle No. 7 on reply card

TRUE RMS METER

Model 320 is a sensitive, wide-range electronic voltmeter designed for ac systems operating at frequencies where it is essential to determine the true root-mean-square magnitudes of periodic complex waves or noise potentials. Operation is not dependent on thermocouples or other thermally sensitive devices; thus the unit is not subject to such drawbacks as accidental burnout, sluggish response, or insensitiveness. Features include a 10-megohm input impedance, simultaneous voltage reading and amplified-signal monitoring, and a built-in calibrator unit which checks the accuracy of the voltmeter without disconnecting the input terminals. Voltage range is 100 microvolts to 320 volts; frequency range, from 5 to 500,000 cps.—Ballantine Laboratories, Boonton, N. J.

Circle No. 8 on reply card



LOW-COST COMPUTER

Shown here is "MAC", an inexpensive compact, and highly accurate electronic computer with great flexibility. The desk-top layout enables the operator to "see" the problem in block form and to vary the coefficient during the problem run. The unit is especially well-suited for the solution of linear differential equations, though may be used in some more difficult nonlinear applications, too. Heath Co., the designer, says it can be operated proficiently within a very short time. Characteristics include a frequency response flat to over 2,000 cps at unity gain, phase shift of less than 1 deg at 1,200 cps, and a power consumption of 450 watts. The complete computer weighs 168 lb and measures 32½ by 26½ by 15 in. Units can be leased or purchased. — Automation Service Co., Hollywood, Calif.

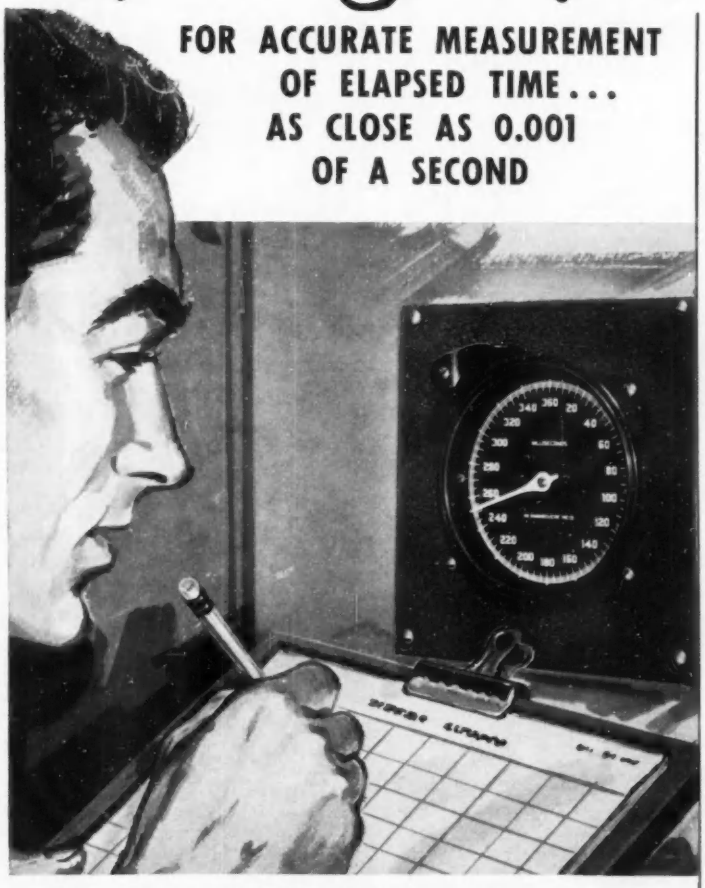
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S-60	1/5 sec.	60 min.	±.1 sec.
SM-60	1/100 min.	60 min.	±.002 min.
S-10	1/10 sec.	1000 sec.	±.02 sec.
S-6	1/1000 min.	10 min.	±.0002 min.
S-1	1/100 sec.	60 sec.	±.01 sec.
MST	1/1000 sec.	.360 sec.	±.001 sec.
MST-500	1/1000 sec.	30 sec.	±.002 sec.

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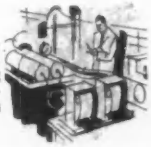


For Glenn L. Martin's ▶ Gunnery Trainer — in 12-channel Playback System designed by Cook Research Laboratories.

▲ Timing test action in automatic transmission research at one of world's largest automotive manufacturers.



▲ At General Electric Co. — Trumbull Division — measuring operating time of circuit breakers.



At Bendix — Westinghouse Research Dept. ▶ laboratories — measuring brake application and release time to 1/100th second.



◀ At American Brass Co. — indicating metallurgical analysis in Direct Reading Spectroscope by Baird Associates.



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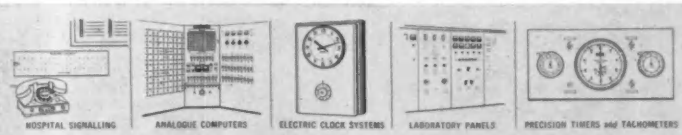
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tube types, the "Missing Pulse Detector" incorporates two input connectors, one for the negative detected RF pulse one for a negative reference trigger. The RF pulse is integrated and used to form a negative gate for squelching the reference trigger. The output in the case of a missing pulse is a positive 15-volt pulse registered on a counter (not part of this set). No output pulses appear if the tube is operating normally. Energy threshold of the detected pulse can be preset in 10-percent steps from 0 to 50 percent of the maximum pulse level, with pulses of lesser amplitude considered missing. Input power requirements are 20 watts at 115 volts, 60 cps.—Manson Laboratories, Stamford, Conn.

Circle No. 10 on reply card

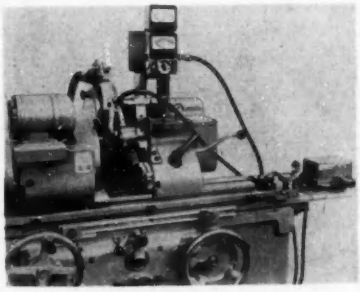
MACHINE-TOOL CONTROL



ACCURATE TO 0.0001 IN.

Digital information, punched into paper tape, automatically operates this vertical precision hole grinder. Developed by Pratt & Whitney for its own precision machine tools, the new numerical control system will accurately position a workpiece to within 0.0001 in. or 5 sec of arc. Easily and economically prepared punched-paper tapes take the place of costly jigs and fixtures. Because it is based on the common decimal system, the controller eliminates the necessity of making mathematical translations. The tape reader uses a pneumatic sensing system. Air is forced through the holes in the tape to an enlarged chamber fitted with a neoprene diaphragm. This provides enough force to operate a reliable industrial-type limit switch. Tape is moved into position and stopped automatically. At this point, all data required for a single operation are read at one time and presented to the machine. When the machine operation has been completed, the tape is advanced to the next block.—Pratt & Whitney Co., West Hartford, Conn.

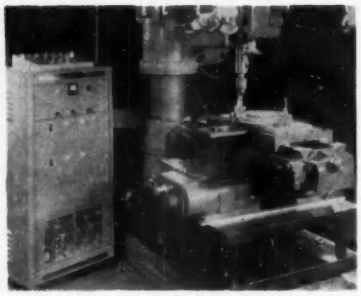
Circle No. 11 on reply card



COMPUTER CONTROL

Based on a new electronic principle which permits automatic computation without sacrificing gaging accuracy, the LI-AP Autopairer, above, can control any grinder to produce external pieces to fit bores within limits of desired radial play. According to the manufacturer, accuracies to within 0.000040 in. can be achieved regardless of the type of grinding machine involved. The device is said to completely eliminate the need for match-gaging or fit-selection. Backlash is electronically compensated. An ID gaging anvil checks the finished bore, and the workpiece is then ground to fit.—EAM Div. of Industrial Gauges Corp., West Englewood, N. J.

Circle No. 12 on reply card



CONTROLLED TABLE

Developed for existing machine tools, a new magnetic-tape-controlled positioning table requires no special operator training. As illustrated above, table motion is along two perpendicular axes

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Design Manufacture Inspection

The Result is Reliable Choppers

It takes all three: design, manufacture, and inspection to produce reliable choppers. Airpax chopper design is the result of years of experience with magnetic-mechanical devices. A resonant reed gives Airpax choppers positive contact action. Materials and their shapes are thoroughly considered in the design of these choppers.

Full potentialities of the design are retained in the finished choppers by careful manufacture. Skilled workers using precision machines assemble Airpax choppers in a completely air-conditioned factory.

And to be certain that Airpax choppers are actually as good as they can be, the materials that go into them are inspected before assembly and the completed choppers are inspected after assembly.

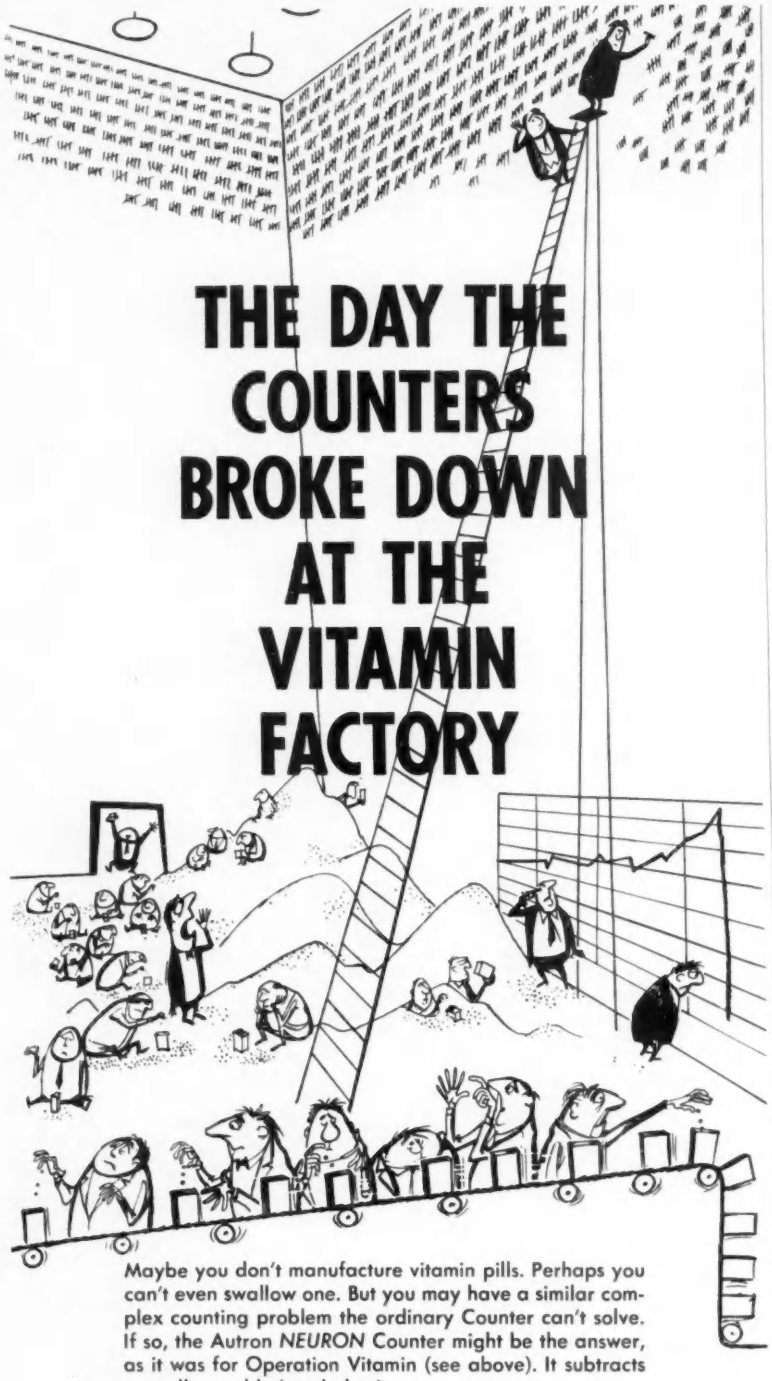
For example, the young lady to the right is placing a chopper in a special Airpax life-test rack where the chopper will be operated for at least its rated life. This rack automatically records the performance of this and other choppers at regular intervals. Any irregular behavior or signs of possible incipient failure will be amplified and plotted on the strip chart along with the life lines of other choppers sampled from production.

This record shows, in terms of hour to hour performance, how effective the design and manufacture are. The result is a reliable chopper.



AIRPAX PRODUCTS COMPANY
DESIGNERS ENGINEERS

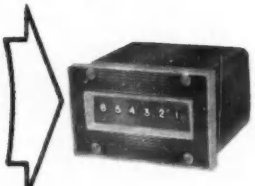
CAMBRIDGE DIVISION, JACKTOWN ROAD, CAMBRIDGE, MARYLAND



THE DAY THE COUNTERS BROKE DOWN AT THE VITAMIN FACTORY

Maybe you don't manufacture vitamin pills. Perhaps you can't even swallow one. But you may have a similar complex counting problem the ordinary Counter can't solve. If so, the Autron *NEURON* Counter might be the answer, as it was for Operation Vitamin (see above). It subtracts as well as adds (see below).

The "NEURON" counters epitomize the most advanced electro-magnetic counter technology, featuring high speed (to 60 PPS), long life (in excess of 300 million cycles), pulse reset, switch readout, bi-directional drive (add and subtract), and small size. These precision units may well be the answer to your tabulation problems.



Autron
ENGINEERING, INC.

For further information, write to Carl Ellis 1254 WEST SIXTH STREET
LOS ANGELES 17, CALIF.
Offices in major cities

in a horizontal plane. Travel at 45 deg to these axes is produced by electrically connecting the axes during recording. The range of motion is 20 by 10 in. and speeds are infinitely variable from 0 to 30 in. per min. Accuracies within plus or minus 0.001 in., maximum table thrust of 1,000 lb. are obtainable. The table measures 50 by 35 by 15 in., the console 22 by 19½ by 48 in. The tape handler will accommodate reels up to 14 in. in diam. This is enough to produce 40 min of table-running time. Tool operation time has no effect since the tape stops during these operations.—Allison Equipment Co., Santa Monica, Calif.

Circle No. 13 on reply card

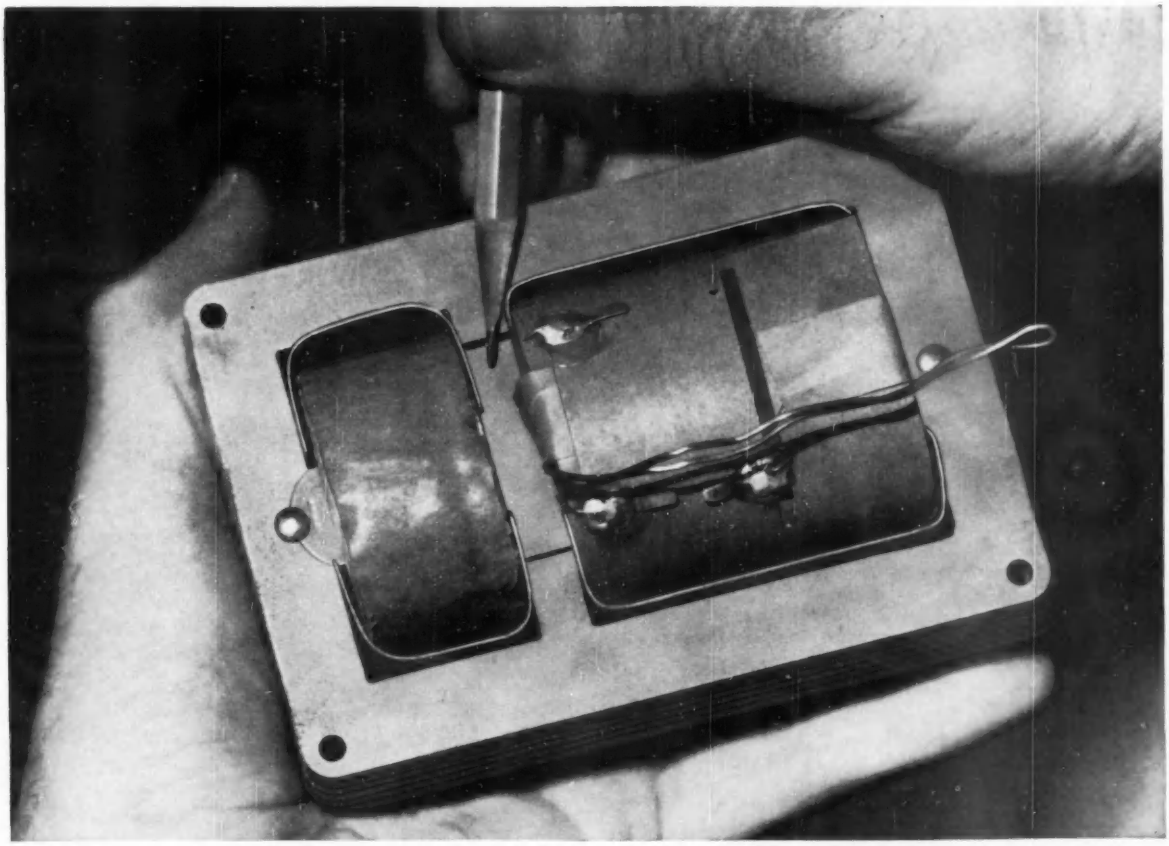
MEASUREMENT & DATA TRANSMISSION



PRESSURE PICKUP

With its pressurized fluid isolated from a dry strain-gage element, this new differential pressure pickup can be used in rocket engines, gas turbines, and chemical processing systems involving corrosive or conductive fluids. Pressure differences are transmitted from a single diaphragm through a mechanical linkage to the unbonded strain-gage element, which is capable of high-frequency performance. Only teflon and 18-8 stainless steel come in contact with the pressurized fluid. Models are available for pressure differentials from plus or minus 0.5 to 1,000 psi, at line pressures up to 2,000 psi.—Dynamic Instruments Co., Inc., Cambridge, Mass.

Circle No. 14 on reply card



PHYSICAL ISOLATION OF INPUT AND OUTPUT CIRCUITS *of the Sola Constant Voltage Transformer is indicated in the core-and-coil assembly shown above. At pencil-point is one of two magnetic shunts which separate the input from the output sections of the windings.*

YOU GET VOLTAGE REGULATION AND MORE FROM A SOLA:

Isolation of Input and Output Circuits in Sola Constant Voltage Transformers Generally Eliminates Need for Static Shields

A fixed level of input voltage to today's complex electrical and electronic equipment is virtually essential for adequate performance. The Sola Constant Voltage Transformer, a static-magnetic stabilizer, combines automatic, instantaneous voltage regulation with other desirable electrical functions.

One of these functions is both electrical and physical isolation of the input circuit from the output circuit. In general, this isolation is sufficiently effective to eliminate the need for additional line filtering. Static shields, often required with regulators having a common connection between input and output circuits, are rarely necessary.

Sola Constant Voltage Transformers are available in stock models, or in custom designs to meet the exact requirements of many load devices or service conditions. Your Sola representative will be happy to provide you with information on your particular application.

SOLA *Constant Voltage* **TRANSFORMERS**



Write for Bulletin 26D-CV170D
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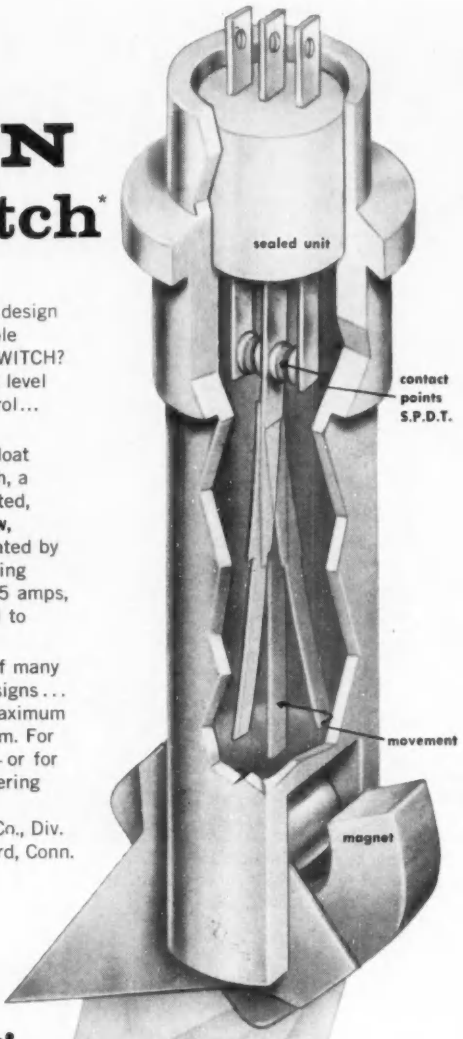
new GORN tip-switch*

(float switch)

Want new simplicity of design ...completely dependable operation in a FLOAT SWITCH? Ideally suited for liquid level indication...pump control... in-flight refueling.

The heart of the Gorn Float Switch is the Tip-Switch, a **sealed,** externally operated, single pole **double-throw, snap acting unit** – actuated by rise or fall of fluid tipping the magnet. Interrupts 5 amps, 18-30 V.D.C. – designed to meet MIL-F-8615.

Tip-Switch is but one of many unique Gorn switch designs... engineered to assure maximum reliability in your system. For more Tip-Switch data – or for complete brochure covering all Gorn switches – write Aircraft Controls Co., Div. Gorn Elect. Co., Stamford, Conn.



tip it...to trip it!

*T.M. Reg. Pat. Pend.



Vertical Dual Float Switch – G2FS400-M1 for internal mounting with two separate systems for either safety or dual level control. Max. wt.: 20 ozs. Overal length in tank: 5".



Miniature Horizontal Float Switch – GMFS400 for internal mounting with horizontal center line at liquid level to be sensed. Max. wt.: 7½ ozs. Overall length in tank: 3".

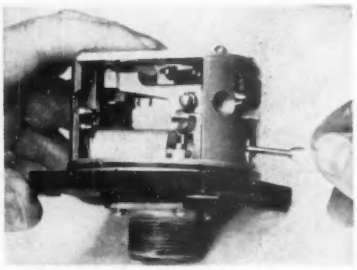
AIRCRAFT division of CONTROLS

Gorn

ESTABLISHED 1923

GORN ELECTRIC CO., INC. STAMFORD, CONNECTICUT

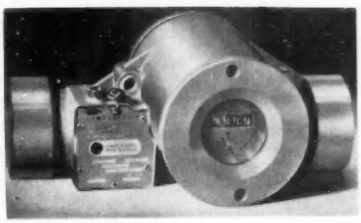
NEW PRODUCTS



RESISTS WEAR

This new accelerometer incorporates a caging mechanism that prevents potentiometer wear when the system is not in use and protects it from abuse in handling and shipping. The mechanism is electrically released as soon as the instrument is in use. Significant features of the rugged unit are its lack of pivots, bearings, or loose springs, its pressure-sealed case, and its high output potentiometer pick-off. Complete unit weighs 18 oz, has an operating temperature range of minus 50 to plus 100 deg C, and can withstand vibrations from 10 to 2,000 cps.–Humphrey, Inc., San Diego, Calif.

Circle No. 15 on reply card



FOR BULK LP GAS

Especially designed for bulk measurements of LP gas, this new 2-in. liquid flowmeter, Model AT3, has a capacity of 25 to 200 gpm and a working pressure of 600 psig. Registration is non-electric and direct on a 6-digit totalizing and nonresettable mechanical counter. Built on the vortex-velocity principle of flow measurement, the meter is accurate within plus or minus 1 percent. There are no clearances to maintain since there are no mating parts. Overall length is only 12 in.; weight is 7 lb. Besides being factory calibrated, the unit has an integral adjustment screw that permits minor calibration to be done in the field.–Rotron Controls Corp., Woodstock, N Y.

Circle No. 16 on reply card

MEASURE MICROVOLTS *without pre-amplification!*

with the New Du Mont type 403



$580.

FEATURING

AMPLIFIERS: Direct coupled amplifiers with single-ended or balanced input.

EXTREME SENSITIVITY: 5 millivolt to 500 volts full scale, continuously variable. Additional sensitivity for short term measurements, with resolution down to 20 microvolts.

FREQUENCY RANGE: DC to 300 KC.

Y AMPLIFIER CALIBRATION: 5%.

SWEEPS: 19 calibrated linear sweeps, 0.5 sec/cm to 0.5 usec/cm. Calibrating accuracy, 5%.

EXPANDED SWEEP: Any 10 cm portion of 50 cm sweep may be expanded 4 times and positioned on screen.

Price **$580.00**
Slightly higher in 50 cycle areas

TYPE 403R Rack mounted version, electrically identical to Type 403 $595.00

Complete Details On Request...

ANOTHER OF THE 400 SERIES

DU MONT

TECHNICAL SALES DEPARTMENT,
Allen B. Du Mont Laboratories, Inc., Clifton, N. J.

The Type 403 is the most sensitive oscilloscope commercially available. It permits direct measurements from low output transducers such as strain gages, pressure pickups, accelerometers, and others that normally require preamplifiers.

When used as a direct reading voltmeter, the Type 403 offers stability of better than 1 millivolt per hour for all ranges from 500 volts all the way down to 5 millivolts full scale. A super sensitive range is available of 1 millivolt full scale (100 microvolts per scale division) for short term measurements.

This outstanding performance is wrapped in the nicest package in the industry. The 403 features "human engineering" resulting in easier operation, complete accessibility and unsurpassed reliability backed by a 5-year guarantee.

NEW

Arnold O. Beckman Gas Density Balance

...for continuous, accurate measurement of process gas streams

Arnold O. Beckman, Inc., announces their new Gas Density Balance designed and constructed for rugged industrial use. This new instrument—known as the Model 3A—gives more sensitive, more versatile and more convenient readings than *any* gas density measuring unit now in use. The Model 3A is not only suited for specific gravity measurements of process streams, but also performs equally well for quantitative measurements of natural gas, H_2, CO_2 or other gases. The Model 3A is a null-balance type instrument which measures gas density by a direct physical principle, assuring rapid and accurate readings.

HERE ARE A FEW OF ITS MANY OUTSTANDING FEATURES . . .

Ranges: Single or multiple ranges with spans from 0.05 to 5.0 sp. gr. relative to air.

Rapid Response: 95% of any reading in less than one minute.

Sensitivity and Accuracy: ±½% of full scale.

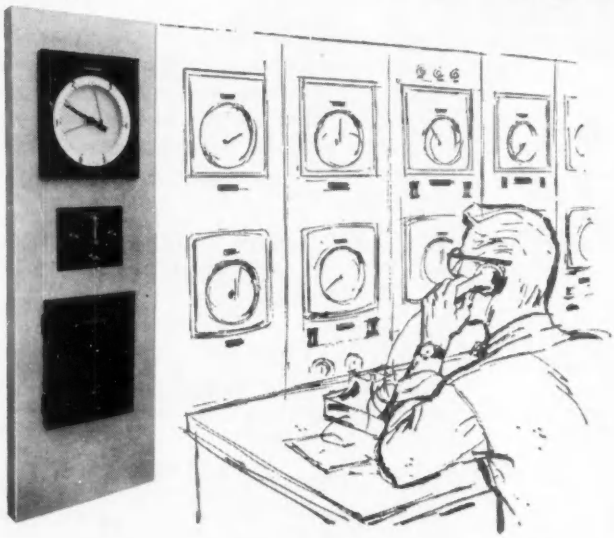
Corrosion Resistant: Measuring element protected against corrosive elements.

Output: 0-5 millivolts standard for use with potentiometer type recorders. Current or pneumatic output available with instruments having single ranges, or two or more ranges having a common end point.

Sample Required: 48 cubic inches per minute at 10 psi.

Power Required: 130 watts with 115 volts, 60 cycles.

The Arnold O. Beckman Gas Density Balance is a single compact unit, designed for wall or flush mounting. The standard steel case is vapor tight, thermally insulated and controlled so that operation is unaffected by ambient temperature changes. The unit weighs about 65 lbs. Explosion-resistant cases are also available.

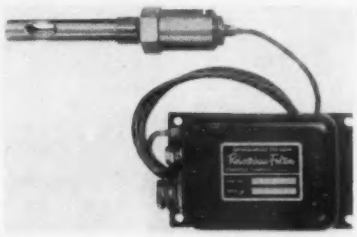


For more information on the Model 3A Density Balance write directly for Data File 22V-47.

Arnold O. Beckman INC.

1020 MISSION STREET • SOUTH PASADENA, CALIFORNIA

NEW PRODUCTS



RUGGED LEVEL SWITCH

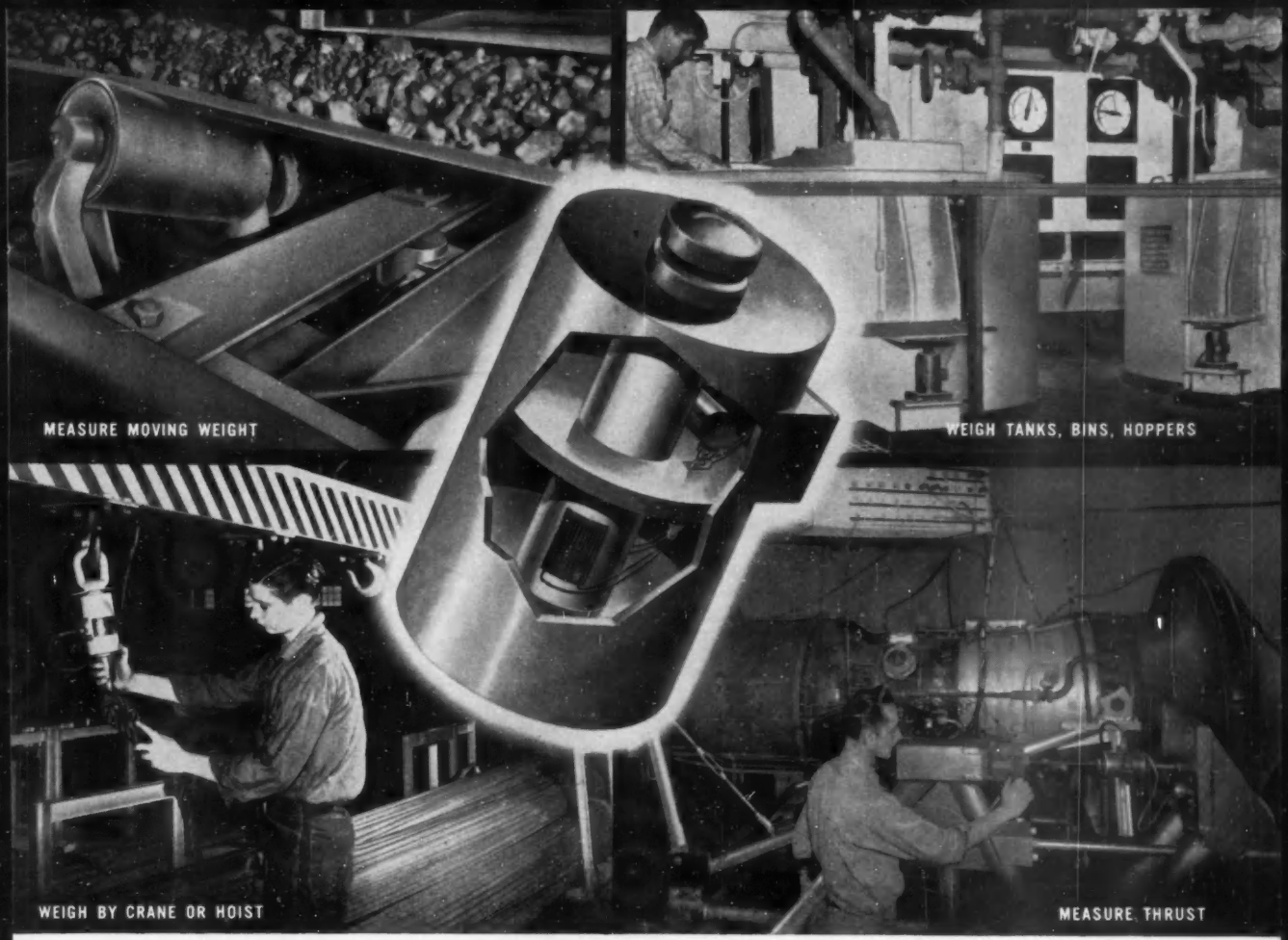
This new liquid-level switch, small, light, and durable, consists of a pencil-size sensing probe containing a hermetically sealed beta source (high-speed electronics) and a beta detector (Geiger-Mueller tube) mounted inside the liquid container. The beta source and detector are separated by a small cavity into which liquid may flow. When no liquid is present, radioactive particles pass from the beta source to the detector tube. Any liquid in the cavity absorbs the radioactive particles, thus reducing the radiation level at the detector. This change is converted to an electric signal which in turn is amplified by a transistorized circuit to actuate a relay. Switch operates on 28 vdc at 0.05 amps.—Robertshaw-Fulton Controls Co., Anaheim, Calif.

Circle No. 17 on reply card



LIGHTWEIGHT RECORDER

This tiny tape recorder is said to have solved one of the most perplexing problems in missile-flight-test programs: that of collecting data from missiles too small for telemetering equipment. To-date it has been used primarily for recording skin temperatures during critical periods in high-speed, high-altitude flights of missiles.



SR-4® LOAD CELLS OFFER YOU NEW ACCURACY—EASE—ECONOMY IN ALL INDUSTRIAL WEIGHING AND PROCESSING

Baldwin SR-4 Load Cells end the costly task of moving loads to and from a weighing unit. Now weigh right in process! Compact Baldwin transducers will measure any tension or compression force—shaft or jet engine thrust—cable tension; determine center of gravity, weight and balance. The applications are virtually unlimited. Weigh loads at rest or in motion. Measurements are accurate to better than ±1/4%; repeatability is better than ±1/10%.

Standard Baldwin SR-4 Load Cells range in capacity from 50 to 200,000 lb. The varying electrical signal from the SR-4 Bonded Wire Strain Gage, basic component of the load cell, can be fed to a wide variety of Baldwin recording or computing equipment.

Whatever your weighing problem, a B-L-H representative can help you. For more information, write today for your free copy of Bulletin 4301 on SR-4 Load Cells.

BALDWIN · LIMA · HAMILTON

Electronics & Instrumentation Division

Waltham, Mass.

SR-4® strain gages • Transducers • Testing machines

DEKORON PRODUCTS CUT INSTRUMENT TUBING COSTS

EASY-TO-INSTALL INSTRUMENT LINE HARNESS



DEKORON Poly-Cor is a tried and proven instrument tubing bundle having advantages of light weight, corrosion resistance and extreme ease of installation.

It is completely color-coded with 7 colors of tubing so placed in the bundle that each tube is easily identified by its relation to the other colored tubes. Their natural resiliency resists physical damage. Harness composed of from 2 to 37 (19 *illustrated*) individual lines is available.

Initial cost . . . installation . . . corrosion resistance . . . maintenance—*no tubing can compare with patented Dekoron Poly-Cor.*

Request Bulletin 456.

Use Dekoron E-Z Tube Fittings. Specifically designed for use with Poly-Cor or with single-line plastic Dekoron "P" Tubing.

AA-4804

Dekoron® products

quality research service

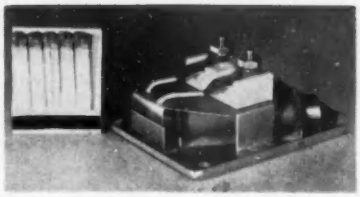
SAMUEL MOORE & COMPANY • MANTUA, OHIO

DEKORON PRODUCTS DIVISION

NEW PRODUCTS

The unit is 4 in. in diam by 5 in. long and weighs only 2¼ lb. One model has been recovered and used eight times.—North American Instruments, Inc., Altadena, Calif.

Circle No. 18 on reply card



FIRE DETECTOR

Developed for use in aircraft baggage compartments, this new thin-shelled, stainless-steel, hermetically-sealed fire detector weighs approximately 4.3 oz. It has a temperature-adjustment range of 50 to 350 deg F, and can withstand exposure to minus 65 deg F indefinitely and to a 2,000-deg-F flame for short periods. Contacts close when the temperature rises above the set-point. Current rating is 5 amp at 125 vac, 2 amp at 28 vdc, and 1 amp at 48 vdc. —Fenwal, Inc., Ashland, Mass.

Circle No. 19 on reply card

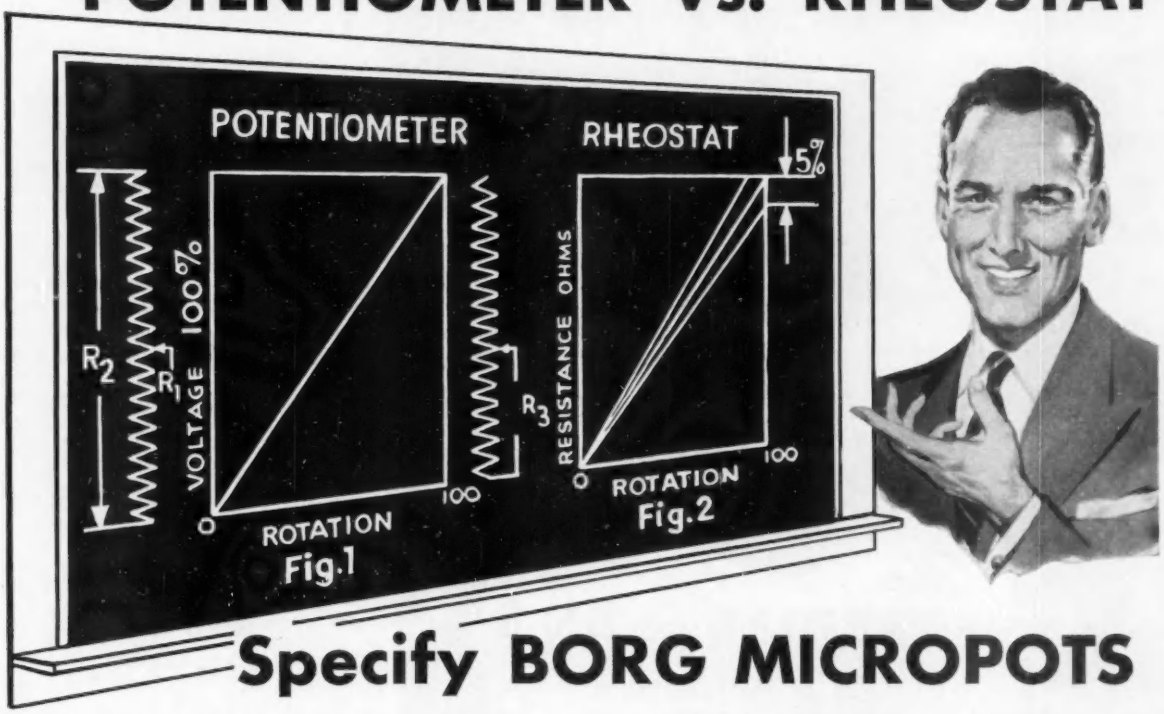


HOLLOW-COIL PICKUP

Shown is a new hollow-coil proximity pickup featuring a connector located on the coil. According to the manufacturer, this permits interchangeability with other models. This particular model uses a hollow phenolic table around which the coil is wound. As a high-frequency, carrier-operated transducer, it works on a principle similar to the military mine detector, sensing aluminum, brass, or copper, as well as iron and steel. The coil can be used as part of a chute or tube through which metal parts, such as screws, nuts, washers, etc., may slide or drop. Fifteen sizes range from ¼ in. to over 3 in. in diam.—Electro Products Laboratories, Inc., Chicago, Ill.

Circle No. 20 on reply card

POTENTIOMETER Vs. RHEOSTAT



Specify BORG MICROPOTS

Potentiometer Vs. Rheostat. Potentiometers should be used whenever possible to reduce systems error and excessive cost. Here's why.

POTENTIOMETER as a POTENTIOMETER

Definition: A potentiometer is a voltage divider.

Accuracy — Potentiometer accuracy is determined by the ratio of R_1 to R_2 for any given position of the control shaft (Fig. 1). Potentiometer accuracy is *independent* of total resistance. Commercial precision potentiometers are designed for use as voltage dividers. Therefore, the total resistance is ± 5%. However, the output voltage is the ratio of R_1 to R_2 and provides a linearity accuracy of 0.1% (Fig. 1). Linearity accuracy in commercial precision potentiometers is 0.1%.

POTENTIOMETER as a RHEOSTAT

Definition: A rheostat is a variable current control.

Accuracy — When used as a rheostat (2 wire hookup) the accuracy of the potentiometer is determined by the absolute resistance R_3 for any given position of the control shaft (Fig. 2).

Rheostat accuracy is *dependent* upon the absolute resistance at any point.

Commercial precision potentiometers, when used as rheostats, have an absolute ohmic resistance R_3. It may deviate from zero to 5% from theoretical over the range of zero to 100% of shaft rotation (Fig. 2). Errors in distribution of this resistance (comparable to potentiometer linearity tolerance) must be added to this error to ascertain the "total ohms per degree conformity", the true measure of rheostat accuracy.

Consider the possibility of a closer total resistance tolerance to provide greater accuracy when used as rheostats. Commercial tolerance on fixed resistance is 5% with special selected values to 1%. This selected accuracy, if duplicated in a rheostat, would still be 10 times greater than the standard 0.1% accuracy of the commercial potentiometer. Factors which contribute to the difficulty in tight total resistance tolerances in fixed resistors are: resistance stability, temperature coefficient, and the absolute ohmic value of commercially available resistance alloys.

These limiting factors apply to potentiometers used as rheostats. This increases the cost of such units just as the cost of tight tolerance fixed resistors is considerably greater than standard tolerances.

We have found, through years of building potentiometers, designing equipment and in consultation with customers, that when systems can be designed to use potentiometers in place of rheostats, greatly increased accuracy results and usually the cost is reduced.

Write for Complete Engineering Data • CATALOG BED-A56

BORG EQUIPMENT DIVISION
THE GEORGE W. BORG CORPORATION
JANESVILLE, WISCONSIN

ELECTRONIC – MECHANICAL BORG EQUIPMENT — Built by Borg

HEAVY-DUTY CONTROL OF MORE

POWER for MOTORS!

POWER for HEATER UNITS!



The GUARDIAN SERIES 2100-U

25 Ampere

POWER RELAY

DIMENSIONS—Length 3⅜". Width 2½". Height 2⅝".
MOUNTING: 2 holes for #8 screws on 1⅞" centers.
WEIGHT—11 oz.

CONTROLS MORE POWER IN LESS SPACE!

Interchangeable Coil Assemblies

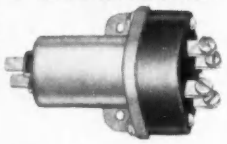
(No solder connections necessary when changing coils.)

In less than six months this relay that introduced 25 ampere power and interchangeable coil assemblies—the Guardian Series 2100-U Power Relay—has become the accepted unit of control for a host of heavy duty applications. Standard unit has D.P.D.T. contacts rated at 25 amperes continuous duty A.C., with 75% power factor. Coil voltages available: 6 to 230 V. A.C., 6 to 220 V. D.C. Operating power requirement 9.5 VA; coil drain approximately .080 amperes at 115 volts, 60 cycles.

Built to Meet U/L Specifications

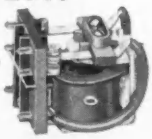
GUARDIAN POWERLOID

For control of 230 V., A.C. loads up to 3 H.P. Motors and 8400 Watt Heater loads. Totally enclosed. Low priced!



GUARDIAN Series 1200 RELAY

Midget 8 ampere unit with up to 3 P.D.T. combinations. Bakelite barriers. Versatile. Built to U/L specs.



write for bulletins

GUARDIAN ELECTRIC

1623-D W. WALNUT STREET CHICAGO 12, ILLINOIS

"Everything Under Control"

NEW PRODUCTS

BALL-DISC INTEGRATOR

Included in Helipot's electromechanical breadboard parts line is a new ball and disc integrator for use in computing systems, servo systems, and rate generators. The ball carriage has a 2-in. maximum travel, and the recommended maximum output torque is 5 oz-in. Torque required to move the ball carriage at its input shaft is 1 oz-in. Maximum disc input torque required at zero load is 3 oz-in., and maximum recommended speed is 1,000 rpm.—Helipot Corp., Newport Beach, Calif.

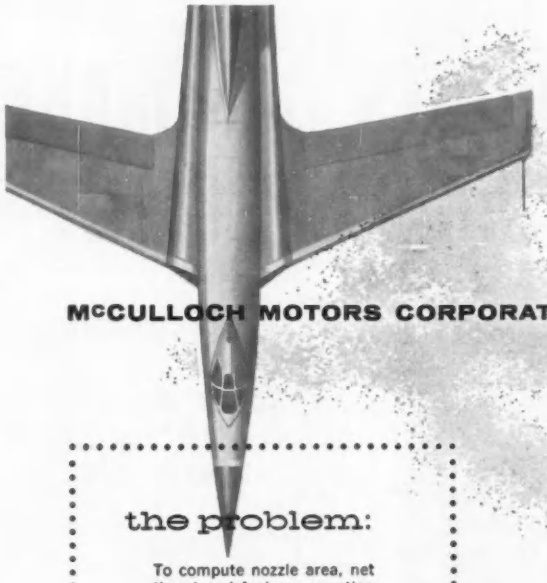
Circle No. 21 on reply card

INFORMATION DISPLAY INSTRUMENTS



ELIMINATES GAGE

Here is a new, inexpensive indicating pressure transmitter that is said to be accurate to within plus or minus 0.5 percent of scale range. Its 4½-in. eccentric indicating scale eliminates the need for a separate field gage. Model 44 measures pressures of 0 to 30 in. of water to 0 to 6,000 psi, transmitting a 3-to-15-psi air signal to indicating, recording, or controlling instruments. Standard elements, such as spirals, helicals, bellows, and diaphragms, accommodate the various ranges. Red pointer and black-on-white scale mark-



McCULLOCH MOTORS CORPORATION

saved 2899 engineering manhours with a Bendix G-15 computer!

the problem:

To compute nozzle area, net thrust and fuel consumption for a new turbine design. 729 sets of answers were required, due to problem variables.

solution:

This problem was essentially unsolvable by conventional methods. The 729 sets of answers would require 2916 manhours on the slide rule, or 10 valuable engineers or mathematicians working for 36 days.

Including programming and check-out time, only 17 hours were required to obtain the 729 sets of answers when McCulloch turned the problem over to the Bendix G-15 General Purpose Digital Computer. **The solution was obtained by one man** and the chance for human error was greatly reduced. But most important, **the engineering time saved was 2899 manhours**... 171 times less than conventional methods. The same type of problem could be solved again in five hours.



New G-15 programming methods suit both the engineer with an occasional problem and the experienced programmer. The INTERCOM system can be learned in just a few hours. As a bonus, an inexpensive accessory adds digital differential analyzer capabilities to the talented G-15. The coupon will bring you further details on the G-15's ability to conserve scarce engineering manhours in a wide range of applications.

Bendix Computer

DIVISION of BENDIX AVIATION CORPORATION

OFFICES IN WASHINGTON, D.C., DALLAS, AND LOS ANGELES

Export Representatives

Computing Devices of Canada, P.O. Box 508, Ottawa 4, Ontario

Bendix International Division, 205 E. 42nd Street, New York 17, N.Y.

BENDIX COMPUTER DIVISION—BENDIX AVIATION CORPORATION
5630 ARBOR VITAE STREET, LOS ANGELES 45, CALIFORNIA

Please send me more details on your Model G-15 General Purpose Digital Computers.

NAME_____

TITLE_____

COMPANY_____

ADDRESS_____

Progress Report:

SCHRADER AIR PRODUCTS CAN MAKE PRECISION OPERATIONS EFFICIENT

● Let's clear the air about close tolerances

We've faced it. Lots of manufacturers still think air is as unpredictable as the weather report. But others know better, because they've taken the time to let a little sunlight on the subject. These open-minded ones are utilizing Schrader Air Products, not just to hold work or blow away chips, but to produce complex units to close tolerances.

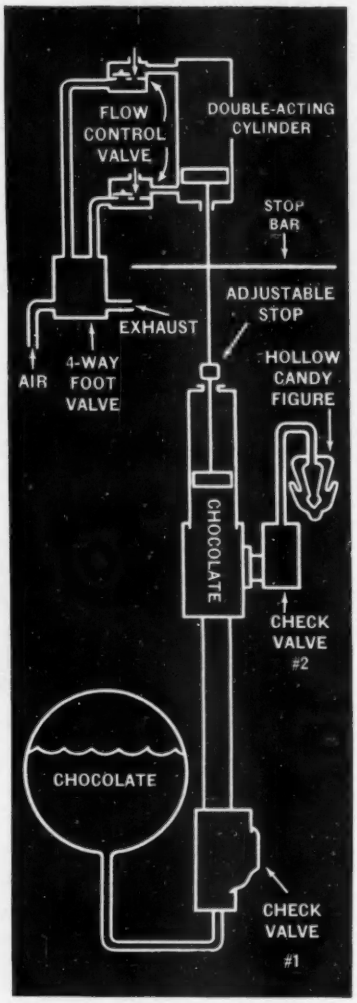
Air is a big boy now. It has grown up fast because automation came because pennies needed pinching. Because many operations in manufacturing turned out to be just plain dangerous. Then engineers found air was not only efficient, economical, and safe, but that products were already designed and produced to make air a logical way of performing hundreds of special jobs.

FOR EXAMPLE:

● Sweet words about air from a candy maker

At a Buffalo, New York, candy company, Schrader Air Products have been used to perform a complex measuring operation. To within one gram! Six Schrader double-acting cylinders are used to fill a bank of six more single-acting cylinders with a prescribed amount of chocolate. When a foot valve is released, the chocolate is forced into wax figurines, exactly filling them. And the entire installation is even covered and kept at a constant temperature to insure the proper chocolate viscosity.

Take a look at the schematic. It shows the arrangement by which the Schrader Air Products are adapted to an operation which might at first seem far outside the limits of air use. It was possible because some engineers put on their thinking caps.



Schematic shows how Schrader Air Products are adapted for precision handling of liquid chocolate.

● Talk about air's advantages being automatic—lend an ear

This is important to you, so don't wander off. When air is used to synchronize motions automatically, efficiency is almost sure to follow. BUT, the natural advantages of air multiply like rabbits. For instance, economy is basic. In many cases it can make the difference between profit and loss. Then, safety margins are widened by the use of special control techniques. Air's simplicity makes possible easy finger-tip and tip-toe operation of tiring hand and foot movements. Fatigue? Who's tired? Production goes up. Modern packaged control sets are so highly developed that most hazards of press operation are no longer applicable. Both hands must be used at once, and cannot stray into danger zones. Any machine using a mechanical clutch, shears, brakes and friction clutches can use special controls.

● We <u>like</u> to be taken advantage of

You can make use of Schrader's engineering facilities. That's why we *have* them. Upon request, Schrader engineers will assist in planning for the most efficient use of air in your plant, and in selecting the products best suited to a given application. Distributors are conveniently located to deliver Schrader Products in the shortest possible time.

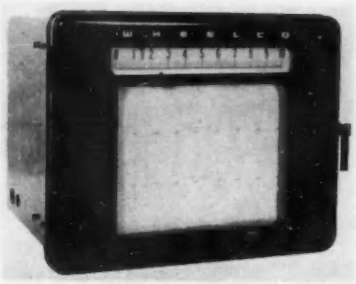
Write to Schrader for information. Address A. Schrader's Son, Division of Scovill Manufacturing Company, Incorporated, 471 Vanderbilt Avenue, Brooklyn 38, N. Y.

Schrader®
ESTABLISHED IN 1844

FIRST NAME IN THE USE OF AIR
FOR INDUSTRIAL PRODUCTION AND CONTROL

ings are visible from as far away as 20 ft. Unit weighs 8 lb, is 8½ in. high, 5⅞ in. wide, and 4⅛ in. deep.—The Foxboro Co., Foxboro, Mass.

Circle No. 22 on reply card



MULTIPOINT RECORDER

Easy to read, easy to operate and easy to service, this new electronic multipoint recorder can permanently record up to 16 points on one chart. A null-balance instrument designed for long life and trouble-free service, it accepts inputs from thermocouples, radiation detectors, and other devices where the measured variable can be resolved into an electrical signal. Up to six limit switches may also be incorporated to provide for high or low signal indication. Four switches may have common front setting means; additional switches are independently adjustable.—Wheelco Instruments Div. of Barber-Colman Co., Rockford, Ill.

Circle No. 23 on reply card

DIGITAL INDICATOR

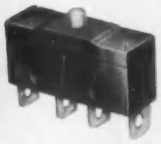
Millivoltage or resistance changes developed by force, flow, weight, and temperature changes are easily read from a new Digital Servo Indicator, the Model 143. Free from parallax and interpolation of reading, the indicator is said to be accurate within 0.1 percent of span. It uses a continuous null balance servo system of operation in a two-case, cable-connected arrangement. The remote case incorporates the measuring circuit, damping network, amplifier, converter, and power supply when necessary. The compact panel-mounted indicator case contains a balancing motor, a slidewire, and the digital counter.—Gilmore Industries, Cleveland, O.

Circle No. 24 on reply card

NOW—

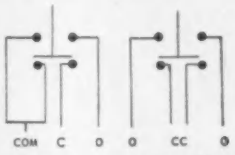
with the

ACRO SUBMINIATURE SWITCH



ACTUAL SIZE

CIRCUIT ARRANGEMENTS



DOUBLE THROW DOUBLE CIRCUIT

Your Choice of 5 New Actuators



LEAF



FORMED LEAF



ROLLER LEAF



PLUNGER



TOGGLE

With its small size, high capacity, and newly-designed actuators, the Acro Subminiature Switch meets an exceptionally wide range of design requirements . . . provides many new development possibilities for subminiature assemblies.

The electrical rating of this precision Acro Snap-Action Switch—10 amperes at 125 or 250 volts A.C. or 28 volts D.C.—is over four times that of most switches this size. It will operate within a temperature range of from +350° to −80°F., and its terminal arrangement permits wiring double circuits.

Switching mechanism is enclosed in a durable plastic case which can also be adapted to various types of present actuators and mountings not shown.

Write for literature, engineering data!



Robertshaw-Fulton CONTROLS COMPANY

ACRO DIVISION

Columbus 16, Ohio

In Canada: Robertshaw-Fulton Controls (Canada) Ltd., Toronto



Pilot Malting Plant and Panel Board of the George J. Meyer Malt & Grain Corp., Buffalo, N. Y.

Important data for malting research recorded on TECHNICAL CHARTS!

This tower-like pilot malting plant is completely automatic, with more than 50 miniature valves, gates, dampers and similar devices. During research on the 10 day cycle of converting barley to malt, variables of temperature and moisture are accurately recorded at 42 points on TECHNICAL strip charts.

Research scientists as well as production engineers the country over rely on the accuracy found in every TECHNICAL chart. They also appreciate TECHNICAL'S ability to supply charts for **all** their instruments, regardless of "make". If you are not already a user, join the thousands who are by specifying TECHNICAL.

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TECHNICAL CHARTS INCORPORATED

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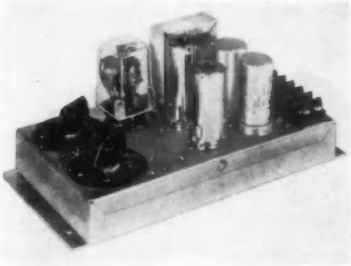
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NEW PRODUCTS

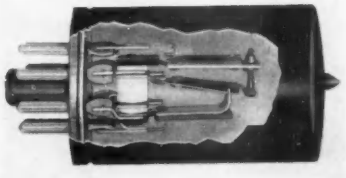
CONTROL DEVICES



THERMISTOR OPERATED

With a differential of plus or minus 0.1 deg F, this Model 63 precision, thermistor-operated temperature controller provides extremely close on-off action. It is smal in size, easily installed and maintained, and low in cost, and is available in several temperature ranges from minus 100 to plus 500 deg F. The unit can be remotely installed, and, for multiple control applications, several of its kind can be grouped in standard conduit boxes. Power supply is self-contained in each unit, and control action is virtually unaffected by line variations between 105 and 125 volts.—Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio.

Circle No. 25 on reply card



NEW TIME RELAY

The Thermal Memory Relay, above, is a thermally operated bistable time-delay relay with single-pole, double-throw snap-action contacts. There are two separate heater circuits, each one serving to transfer a movable arm from one contact to the other. Operating time is factory preset for either 20 or 30 sec on both transfers. Relays are temperature compensated from minus 55 to plus 100 deg C, and have ratings of 6.3, 26.5, or 117 volts. Each heater has 2.7 watts power. Curtiss-Wright Corp, Electronics Div., Carlstadt, N. J.

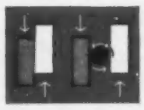
Circle No. 26 on reply card

SAGINAW b/b SCREWS are guaranteed 90% EFFICIENT!

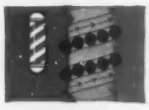
Require 4/5 LESS torque than Acme Screws for same linear output on Actuator and Positioner Applications! Saves space, weight!



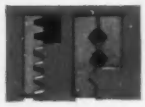
WHAT IT IS AND HOW IT WORKS



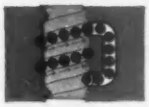
Let's start at the beginning, with the familiar principle that there's far less friction in *rolling* than in *sliding*. By applying this principle,



Like stripes on a barber pole, the balls travel toward end of nut through spiral "tunnel" formed by concave threads in both screw and mating nut.



the *Saginaw ball/bearing Screw* radically increases the efficiency of rotary-to-linear motion (and vice versa). Instead of *sliding*, mating surfaces *glide* on rolling steel balls.



At end of trip, one or more tubular guides lead balls diagonally back across outside of nut to starting point, forming closed circuit through which balls recirculate.

SIX DESIGN ADVANTAGES

1. Vital Power Savings. Permit much smaller motors with far less drain on electrical system, simpler circuitry.

2. Space/Weight Savings. Screws themselves are smaller, lighter; permit smaller motors and gear boxes; eliminate auxiliary equipment required by hydraulics.

3. Precise Positioning. Machine-ground type will position components far more precisely than hydraulics or pneumatics; tolerances on position are held within .0006 in./ft. of travel.

4. Temperature Tolerance. Normal operating range from −75° to +275° F.; in selected materials, will function efficiently as high as +900° F.

5. Lubrication Latitude. If lube fails, will still function with remarkable efficiency. Units have been built and qualified for operation without lubrication.

6. Fail-Safe Performance. Far less vulnerable than hydraulics; Gothic-arch grooves, yoke deflectors and multiple circuits provide added assurance against failure.

SAGINAW b/b SPLINE



Utilizing the same basic *gliding ball* principle, Saginaw has developed the *Saginaw b/b Spline* which radically increases the efficiency of transmitting or restraining high torque loads.

Averages 40 times lower friction coefficient than sliding splines!

It can be fitted with integral gears, clutch dogs, bearing and sprocket seats, etc., for use with a wide variety of electrical units. Units have been built from 3 inches to 10 feet long—⅜ to 6 inches in diameter.

Available in custom machine-ground and stock rolled-thread types. Units have been built from 1½ inches to 39½ feet long—⅜ to 10 inches in diameter.

Saginaw ball/bearing Screws & Splines

SAGINAW STEERING GEAR DIV., GENERAL MOTORS CORP., SAGINAW, MICH.

SEND COUPON FOR NEW 1957 ENGINEERING DATA BOOK

or see our section in Sweet's Product Design File



Saginaw Steering Gear Division, General Motors Corp.
b/b Screw and Spline Operation
Dept. 6V, Saginaw, Michigan

Please send new engineering data book on Saginaw b/b Screws and Splines to:

NAME_____

COMPANY_____ TITLE_____

ADDRESS_____

CITY_____ ZONE____ STATE_____



PHOTO - COURTESY SERVICE PIPE LINE COMPANY

VAREC PULSE CODE RECEIVER INSTALLATION AT FT. LARAMIE STA. OF SERVICE PIPE LINE COMPANY

"Varec" PULSE CODE telemetering

Tailored To Your Needs...

In addition to giving an accurate signal on liquid level readings over long distances and doing it in the record time of 5 seconds, the "Varec" PULSE CODE Telemetering System can now perform a great variety of operations. Some idea of the system's flexibility can be obtained by checking these optional features:

1. Pulse Code Receivers with provisions for indicating liquid level, temperature, motor valve or other equipment status, abnormal or alarm conditions and other data as required.
2. Systems incorporating two or more receivers.
3. Systems incorporating two or more receivers and selectors.
4. Receiver with terminal provisions for connecting with data printer
5. Digital clock to be used in conjunction with data printer.
6. Serial entry data printer such as an electric typewriter.
7. Parallel entry data printer such as a ribbon type adding machine.
8. Data Programmer to link Pulse Code receiver to data printer
9. Contactor units to provide "on – off" remote control of equipment such as pumps, motor-driven valves, etc.
10. Scanner unit to provide automatic scanning for data logging on a pre-determined time schedule.

With this wide selection of combinations, your "Varec" PULSE CODE System can be custom-built for your particular process..

Write for "Varec" Bulletin CP-3011 for full details of "Varec" PULSE CODE Telemetering.

961-20

THE VAPOR RECOVERY SYSTEMS COMPANY

"Varec"

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Varec Compton Calif (U.S.A.) All Codes

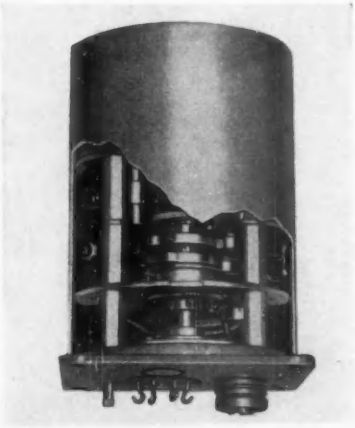
NEW PRODUCTS



PRESSURE SWITCH

This new differential pressure switch is designed to make or break electrical circuits when the difference between two pressures equals or exceeds a predetermined value. The unit features low and high operating pressures of 250 psig and 500 psig, respectively, and weighs only 0.75 lb. Pressure differentials are sensed by a diaphragm-type capsule designed to withstand high overpressures without sacrificing sensitivity.–Gulton Industries, Inc., Metuchen, N. J.

Circle No. 27 on reply card



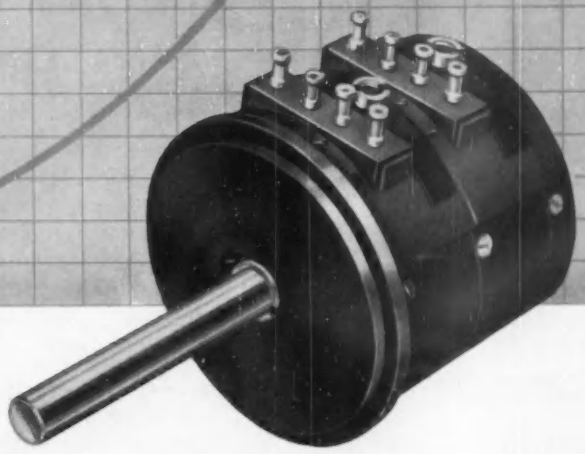
SEALED TIMER

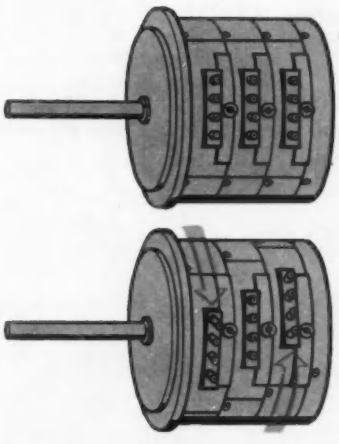
This hermetically sealed time-delay relay weighs approximately 30 oz and meets all environmental requirements for aircraft and ground installations. Units are available with from one to six contacts and with time cycles from fractional seconds to multiple hours. A synchronous timing motor is used

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Simplified phasing! External independent phasing of each cup, without affecting relationship of others. To phase, loosen nut, adjust cup, tighten nut. That's all. Adjustments can be made before or after mounting. Elimination of clamping ring reduces overall diameter.

New and better variable, single-turn precision potentiometers. In single and ganged units. Mounting as per A.I.A. (Aircraft Industries Associated); other mountings available.

Clarostat Vari/Phase Potentiometers meet or exceed A.I.A. electrical and mechanical requirements. Materials selected for lightest weight consistent with rugged construction. Design assures highest performance. In five sizes — 7/8″, 1-1/16″, 1-5/8″, 2″ and 3″ diameters.

Technical Details On Request.
LET US QUOTE.

CLAROSTAT®

CLAROSTAT MFG. CO., INC.
DOVER, NEW HAMPSHIRE

Check and double check your level WITH



F-8480 weighs only 1.75 lbs. . . . operates 1.05" to 4.90" range . . . from —65 to 160 deg. F. Includes two hermetically sealed relays, SPDT, 3 amp motor load at 28 volts DC, 100,000 cycles minimum. Conforms to MIL Specifications. Heater unit (extra) for extreme temperature-humidity conditions.

REVERE DUAL FLOAT SWITCHES

Revere dual float switches have multiple applications. Used for automatic cut-off control in refueling operations, remote indication of fuel or fluid level in tanks, automatic C.G. control to actuate pumps or valves.

Revere Dual Float Switches allow use of two separate systems either as emergency or two-level control. Floats are only moving parts . . . non-absorbent for long-time accuracy. Permanent magnets in float actuate hermetically sealed Glaswitch* at precise levels. Vibration-proof, slosh-proof. Many types available.

* Trademark



F-70140 weighs 1.50 lbs. . . . for —65 to 160 deg. F. use. Contains one DPDT hermetically sealed relay. Rating—2½ amp at 28 volts DC, 100,000 cycles minimum. Pre-check coils permit testing of switch when tank is dry. Conforms to MIL Specifications.

Ask for Engineering Bulletins 1050 and 1051 describing Revere Float Switches.



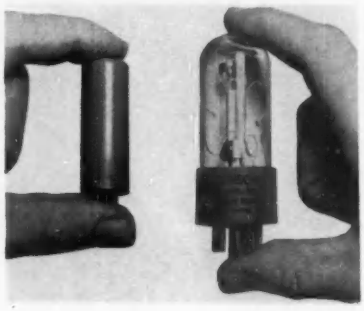
Revere CORPORATION OF AMERICA 19

WALLINGFORD, CONNECTICUT A Subsidiary of Neptune Meter Company

NEW PRODUCTS

for 60- and 400-cycle applications. For dc applications, either a permanent-magnet type motor or a governor controlled motor may be used.—Eagle Signal Corp., Moline, Ill.

Circle No. 28 on reply card

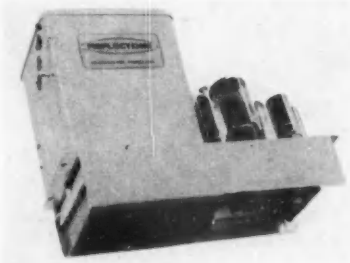


DELAY RELAY

Above is a new vibration-resistant thermal delay relay specifically designed for missiles and jet aircraft. The design virtually eliminates contact chatter up to 1,500 cps at 10 g's, prohibits resonance to 500 cps, and provides for good ambient compensation between minus 65 and plus 85 deg C. Contacts are rated for 1 amp at 27.5 vdc or 3 amp at 115 vac; rigid construction allows for high contact pressure. Permanently calibrated and sealed in a metal shield, these units are available in standard heater voltages and a number of time delays.—Thomas A. Edison Industries, West Orange, N. J.

Circle No. 29 on reply card

POWER SUPPLIES



ADJUSTABLE POWER

Two new electronic subchassis power supplies have different output voltages.



You can't buy this seal of approval . . . you've got to earn it. You've got to be able to produce quality. Daystrom Instrument is doing it every day. Daystrom is proud of the quality record it has established in the industry . . . and with all branches of the armed services. Fire Control Systems, Communications Systems, Attack Directors, Mine Detecting Devices, Servo Control Systems, Pilot's Dead Reckoning Indicators, Missile Test Equipment, Jet Engine Components and Assemblies and other critical electronic and electro-mechanical devices are but a few of the quality products that have been made by Daystrom Instrument.

DAYSTROM INSTRUMENT *Division of Daystrom Inc.* ARCHBALD, PENNA.



he's working for you

THIS FELLOW IS TRAINED IN YOUR BUSINESS. His main duty is to travel the country — and world — penetrating the plants, laboratories and management councils . . . reporting back to you every significant innovation in technology, selling tactics, management strategy. He functions as your all-seeing, all-hearing, all-reporting business communications system.

THE MAN WE MEAN IS A COMPOSITE of the editorial staff of this magazine. For, obviously, no one individual could ever accomplish such a vast business news job. It's the result of many qualified men of diversified and specialized talents.

AND, THERE'S ANOTHER SIDE TO THIS "COMPOSITE MAN," another complete news service which complements the editorial section of this magazine — the advertising pages. It's been said that in a business publication the editorial pages tell "how they do it" — "they" being all the industry's front line of innovators and improvers — and the advertising pages tell "with what." Each issue unfolds an industrial exposition before you — giving a ready panorama of up-to-date tools, materials, equipment.

SUCH A "MAN" IS ON YOUR PAYROLL. Be sure to "listen" regularly and carefully to the practical business information he gathers.

McGRAW-HILL PUBLICATIONS

NEW PRODUCTS

Output for the Model PS-S150 is 150 volts, 150 ma dc, or 6.3 volts, 6 amp ac. For the Model PS-S300 the output is 300 vdc. Input for both is 115 volts, 60 cps. Dc regulation is within 0.5 percent for 10-percent line variation, and within 1.0 percent from no load to full load. — The Reflectone Corp., Stamford, Conn.

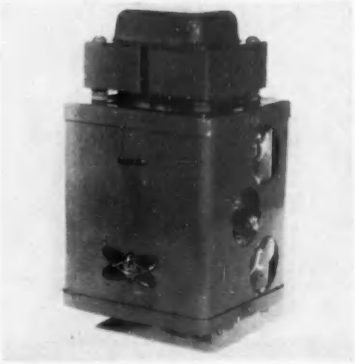
Circle No. 30 on reply card



TUBELESS 15-AMP SUPPLY

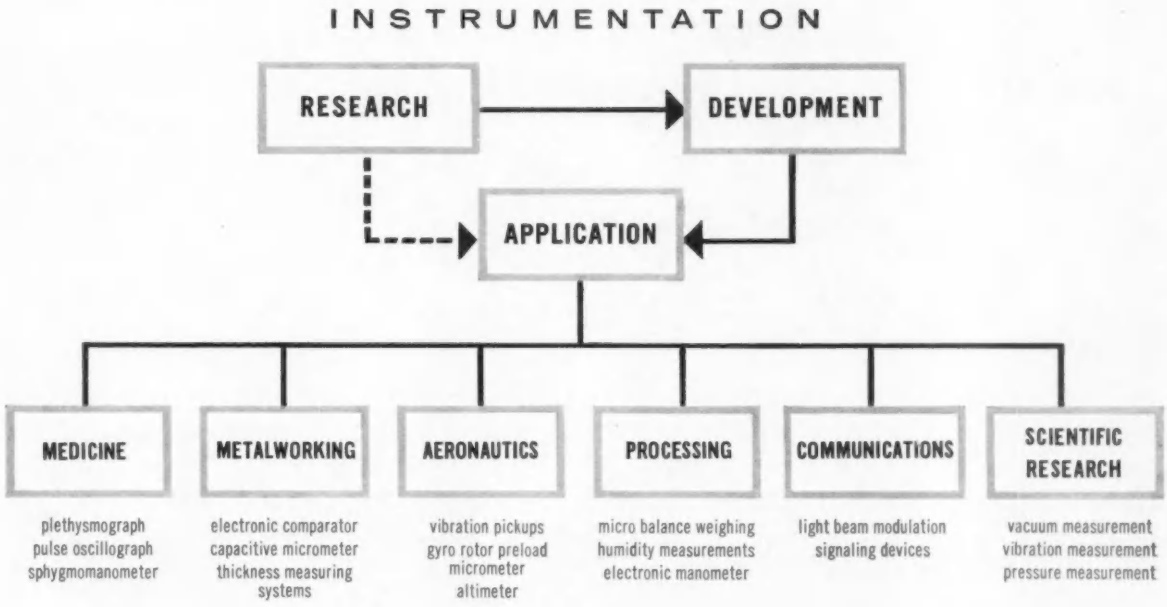
This 15-amp regulated dc power supply, compact, lightweight, and containing no moving parts, has a voltage range of 2 to 36 vdc. Between 5 and 32 volts can be regulated within ½ percent, between 2 and 5 volts and between 32 and 36 volts within 2 percent. Unit takes an ac input from 105 to 125 volts, and has a maximum response time of 0.1 to 0.2 sec. Including the cabinet, it weighs 110 lb, measures 20¼ in. wide by 16⅝ in. deep by 13¾ in. high.—Perkin Engineering Corp., El Segundo, Calif.

Circle No. 31 on reply card



VOLTAGE REGULATED

The Model 223 is a voltage-regulated power supply for photomultiplier



an idea is the solution to every problem

Decker Aviation is a company of ideas.

Not long ago, for example, Decker took the idea of an ionization transducer and brought the idea to reality . . . then used it imaginatively to solve pressing problems in any number of far flung fields.

In medicine, Decker applied the transducer to the improvement of such basic instruments as the plethysmograph . . . giving medical researchers a new magnitude of sensitivity in their explorations.

For geophysical research, Decker ideas made possible instrumentation that, mounted in the nose of an Aerobee-Hi rocket reaching an altitude of 125 miles, continuously and accurately measured both ram and ambient atmospheric pressures at speeds in excess of a mile per second.

Applying new ideas to the micrometer comparator, Decker gave the production line an instrument for measuring an object without physical contact to within a few millionths of an inch.

All the examples listed on this page hardly begin to show the extent of Decker accomplishments. For one problem after another, we have found the idea . . . developed it into a solution . . . built prototypes . . . even manufactured finished instruments.

We would honor an opportunity to evaluate your problems. Our ideas may very well be their solution.

DECKER AVIATION CORPORATION

Philadelphia

NO ONE FILTER MEETS ALL DESIGN NEEDS . . .

and Only CUNO offers you

5 DISTINCT TYPES OF FILTER MEDIA

♦ EDGE-TYPE ♦ WIRE-WOUND ♦ SCREEN
♦ FIBER CARTRIDGE
♦ POROUS METAL

THE New WHITE CELLULOSE **MICRO-KLEAN®** FILTER CARTRIDGE

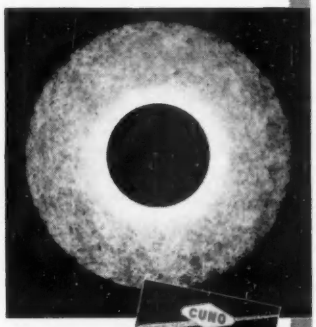


Where Filter Design Calls For—

5-MICRON FILTRATION . . . removes *all* particles down to this size *and* a large percentage of particles down to 1 micron or smaller.

COMPLETE SANITATION . . . for water, liquid food processing and other applications where *clarity, purity* and complete absence of any filter-imparted *taste* are essential.

EXCLUSIVE "GRADED DENSITY" construction makes entire depth of cartridge body available for micronic filtration . . . *doubles* cartridge life, cuts replacement costs *in half!*



COMPLETE DESIGN-ENGINEERING SERVICE

There is a Cuno Field Engineer located in your area. To help solve your design problems, this trained specialist offers you *more years of experience* in removing *more sizes of solids* from *more kinds of fluids.*



New DESIGN DATA . . . MICRO-KLEAN FILTER *combines fine filtration and high flow rates with important time- and space-saving advantages. Write now for your free copy of Catalog No. 53-100.*

CUNO

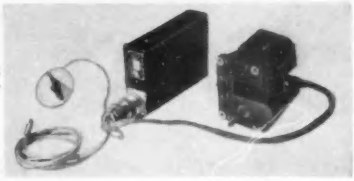
CUNO ENGINEERING CORPORATION
2704 SOUTH VINE STREET, MERIDEN, CONN.
Filtration Engineers in Principal Cities

NEW PRODUCTS

tubes. Output voltage is 1,500, plus or minus 25 volts. A slotted shaft potentiometer in the rear of the unit permits rapid voltage adjustment. Unit features line regulation within 0.1 percent, ripple less than 50 mv, a maximum allowable current drain of 1.5 ma, and line voltage limits of 105 to 125 vac, 60 cps.—C. J. Applegate & Co., Boulder, Colo.

Circle No. 32 on reply card

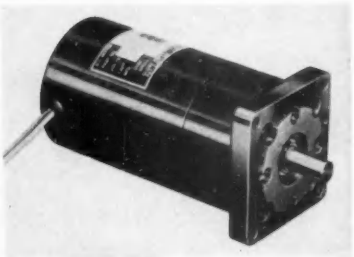
FINAL CONTROL ELEMENTS



REMOTE POSITIONER

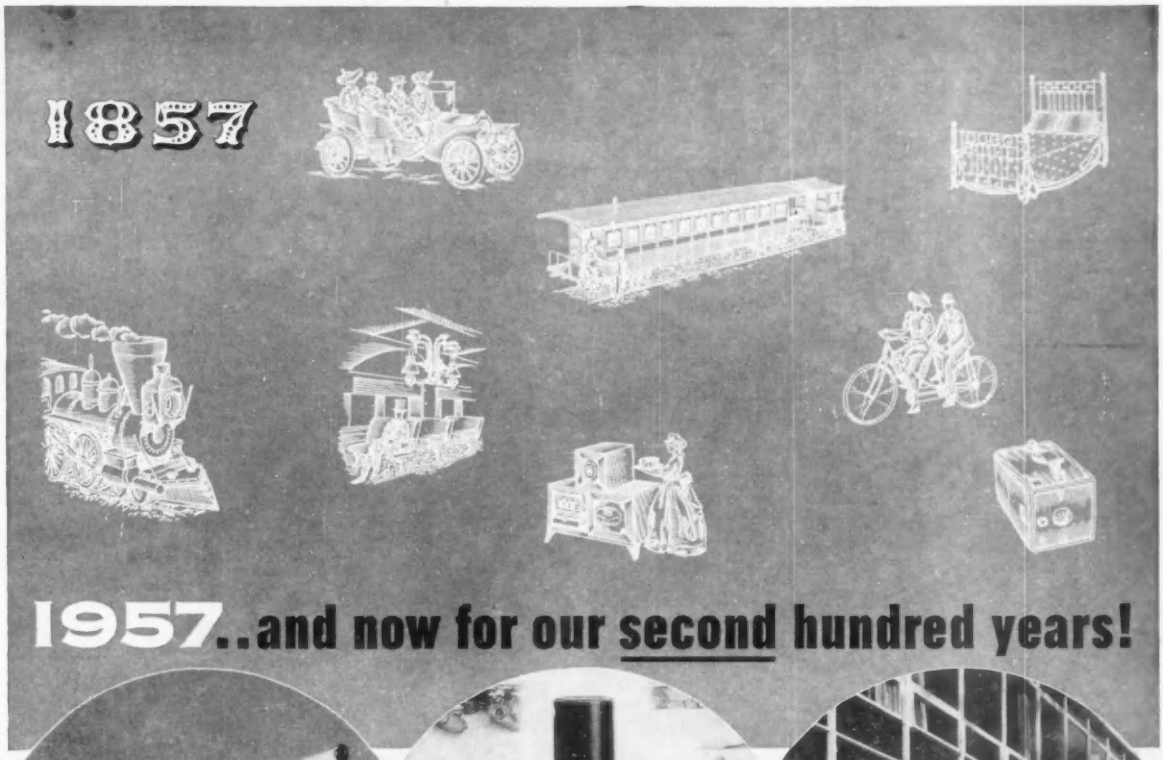
The industrial-type Electrolink is a remote positioner that operates on standard 60-cycle power and has rapid response with high accuracy. The unit compact weighs only 16 lb, and is adjustable to varying requirements. It reaches maximum speed in 1/50 sec and is accurate to within ½ deg. Basic components include: a data link, which converts manually-positioned input into error voltage; an amplifier, which processes signals from the data link and a velocity signal from the servo drive; and the servo drive itself, which incorporates an integral generator and provides power output to the load.—Lear, Inc., Grand Rapids, Mich.

Circle No. 33 on reply card

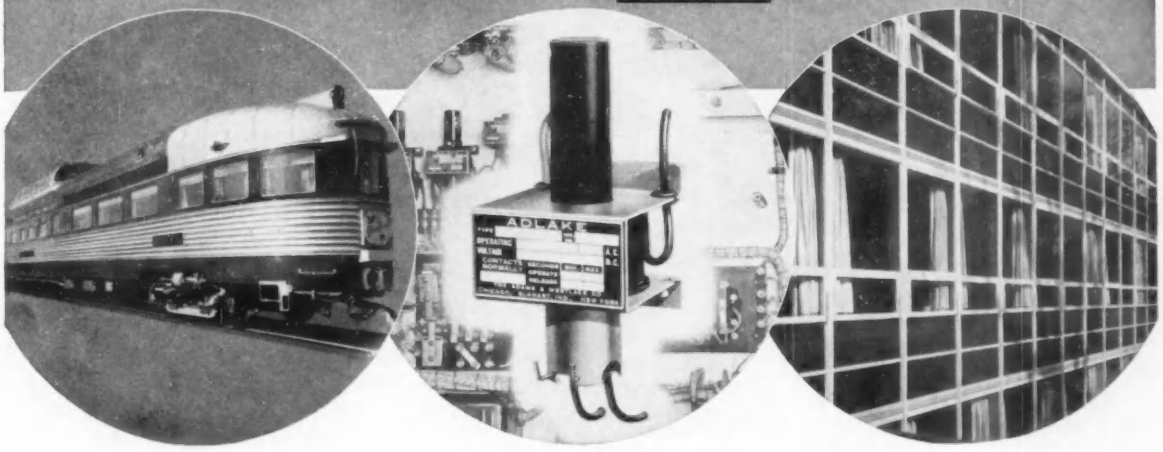


102 SPEED RATIOS

Shown is one of a new line of stand-



1957..and now for our second hundred years!



A lot of history has passed in our first hundred years. We have seen sweeping changes take place in every area of human experience. But Adams & Westlake has not changed in policy or in dedication to the maintenance of product quality.

Every Adlake product must be as excellent as our 100 years of know how can make it. This assures continuing growth for us and better products for our customers in the transportation, electronics and building construction industries.

Adlake
THE ADAMS & WESTLAKE CO.
100th ANNIVERSARY
1857-1957

The Adams & Westlake Company

NEW YORK ELKHART, INDIANA CHICAGO

6000 PSI

wide range, high-flow regulator

maintains high degree of accuracy with regulated pressures from 0 to 5000 psi!



performance features:

- Normal inlet pressure of 6000 psi!
- Wide adjustment range of 0 to 5000 psi with extreme sensitivity!
- Burst — 15,000 psi!
- Maximum required handle torque 30 inch lbs. due to planetary gear system in handle!
- Adaptable for use with air, nitrogen, helium and gaseous oxygen!
- ¼" tube straight thread gasket seal bosses per AND10050!
- Also available in AND10053 ¼" pipe thread!
- Internal valve and filter are removable without disturbing spring, diaphragm structure!
- Internal relief valve adjustable over entire outlet pressure range!
- Internal 5 micron filter!
- Bubble-tight shut-off!
- Adjustable mounting!

Please send me engineering data information on:

Part 110700—Air, nitrogen, helium. _____

Part 111700—Gaseous oxygen only. _____

APCO

ACCESSORY PRODUCTS CORP.
Dept. C4, 616 W. Whittier Blvd.
Whittier, Calif. Phone: OXford 3-3747

ard motors operating on 115 or 200 vac, 60 or 400 cps. They are wound for two-, four-, or six-pole single- or two-phase operation, and for two- or four-pole three-phase operation. Integral planetary gearing is used for speed reduction. At present, 102 ratios between 4 to 1 and 3 million to 1 are available. Varying the speed of the basic motor gives up to 306 standard output speeds. Units are supplied with induction rotors producing up to 3.5 in.-oz of torque, or with hysteresis rotors that produce up to 1.2 in.-oz of torque at synchronous speed.—Globe Industries, Inc., Dayton, O.

Circle No. 34 on reply card



ELECTRO-PNEUMATIC

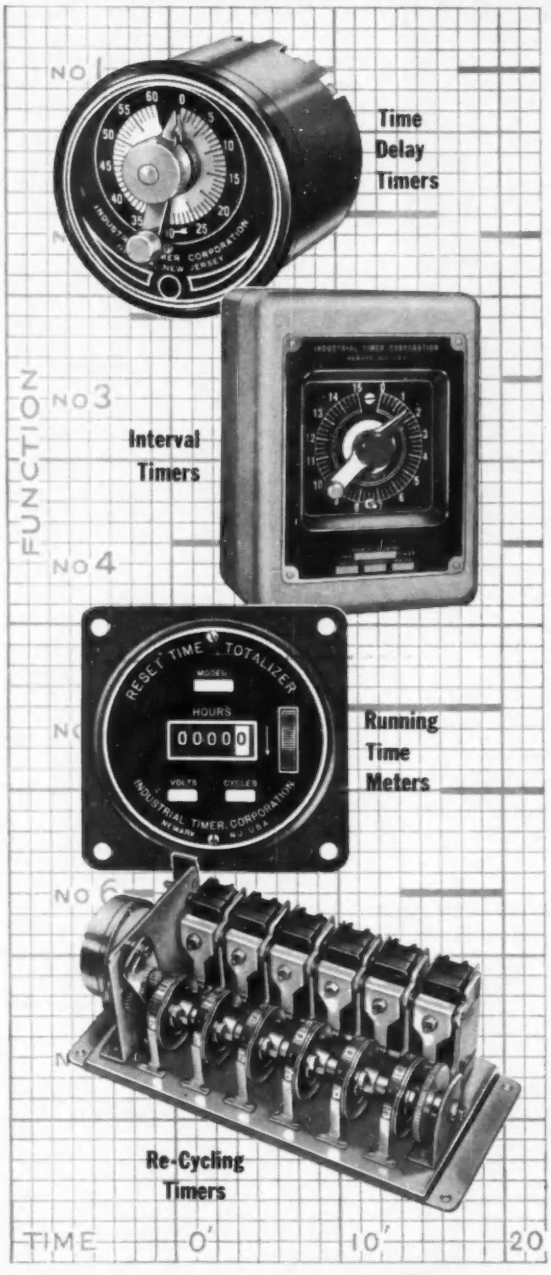
The Model "E" ElectroPneumatic positioner, shown here, provides valve positioning directly proportional to dc signals received from electronic instruments. No electro-pneumatic transducer is required, and full 100-psi plant air supply can be used. The new unit is said to be as sensitive and stable as the company's pneumatic positioner, and at the same time to be able to eliminate the inherent transmission lag of all-pneumatic systems. Units are now available as integral components of the control valves.—Conoflow Corp., Philadelphia, Pa.

Circle No. 35 on reply card

NEW MOTOR-GEARHEAD

This high performance 400-cycle servo unit operates directly from either a 115- or 26-volt line. Motor and gear-

Need a "SPECIAL" TIMER ...need a "STANDARD"?



Here's why WE can give you the fastest service

When you want a timer, you want one that fits your needs 100% — and you want it *fast*. Get in touch with Industrial and you'll get both. Because:

In our 20 years of experience, we have developed over a *thousand combinations* from our 17 basic types, to meet the widely varying needs of our customers. Therefore — many jobs that would seem to require a "special" timer are in fact a "standard" timer with us. Here is one tremendous saving of time for you.

When you *do* need a special timer, this same wealth of experience goes to work for you at once to design it. Our Engineering Department not only originates new designs, but also develops modifications for that purpose. That's why requests for special timers can be filled without delay.

Each method — designing for a standard timer or for a special timer — has its advantages. Designing for an already available timer means lower costs, faster service, simplified replacements.

Designing for a special timer has its advantages too. It means you'll fulfill your needs 100% — no need to limit your designing horizons. Either way — standard or special — you'll get the timer you want most promptly from Industrial.

Or perhaps you need quick service on timers for automatic controls. Here too Industrial Timer is your first source of supply. For in this field Industrial has a big head start. True, each automatic control job is a bit different from the rest. But the record shows that our years of timer experience has given us the special knowledge it takes to give you the right answers in near-record time.

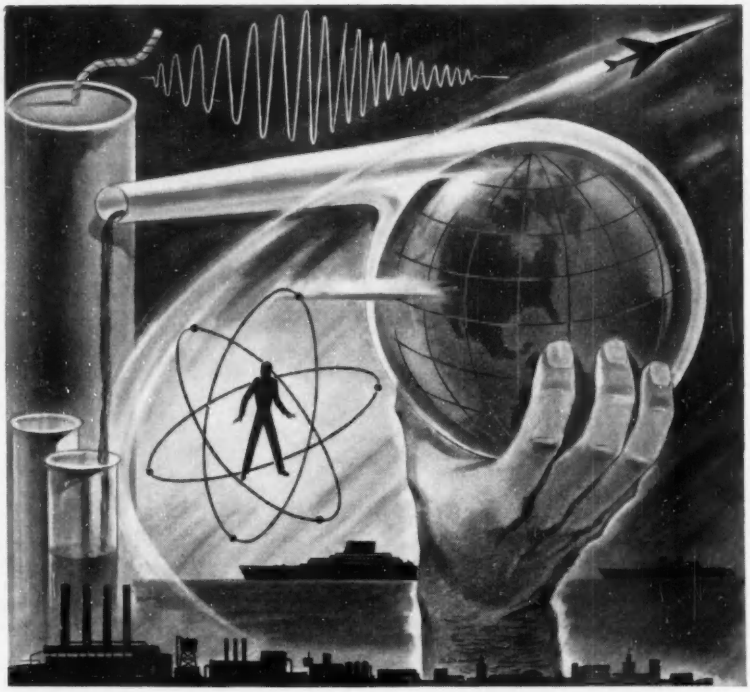
So, for the utmost in all-round timer service, it's Industrial that offers you this outstanding combination: deliveries "Immediate on Standards . . . First on Specials." Plus the experience of one of the foremost group of timer engineers in the nation.

Timers that Control the Pulse Beat of Industry

INDUSTRIAL TIMER CORPORATION

INDUSTRIAL TIMER CORPORATION

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Conquering Man's Conquest of Man

Today the great scientific brains of the world are engaged in pursuits whose fruits are the miracles of technological advancement. Comfort, safety, health, security—in all areas, great forward strides are being made by industry, by science and by (sigh) engineering.

At Sigma there has not been lack of awareness of the manifest destiny of man to free himself from the shackles of retrogression. The same Sigma thinking (we call it Sigmagineering) that gave Sigma Sensitive Relays to the world has now been directed toward the more serious problems of saving mankind from self-destruction. Our part is small, but perhaps it will be the little ocorn that will prevent the great aches from getting mightier.

Sigma's contribution to this worthy cause is the Aurelius P. Zindbasky Do-it-yourself Kit #1 for Finder Fixing (named for the Sigmagineer who invented it). It is instantly available, cost reasonable, benefits immeasurable. In less than one-half hour *you* can remove, with an A.P.Z Kit #1, the unsightly fins on the rear finders of your late model car. Here are actual photographs of the results before (left) and after (right) use of an A.P.Z #1:



BEFORE AFTER

Although not a standard Sigma product, we are prepared to supply A.P.Z Kit #1's on receipt of 78c (78c) in late model coins. Don't delay—this may be the turning point of your life.

SIGMA INSTRUMENTS, INC.
69 Pearl St., So. Braintree, Boston 85, Massachusetts

ONE OF A SERIES OF ONE ADVERTISEMENTS DEPICTING SIGMA'S PLACE IN THE AMERICAN SCENE AND REPORTING ON ADVANCES IN FIELDS, THOUGH NOT EXACTLY BILATERAL TO SIGMA'S REGULAR FIELD, NEVERTHELESS.

head are enclosed in a common housing to minimize alignment and assembly problems, and to reduce size and weight. The unit can be supplied, at no increase in length, with an integral slip clutch to protect gearing and loads. This feature is especially important when one is confronted with the high stall torques resulting from the use of high gear ratios.—Servomechanisms, Inc., Westbury, L. I.

Circle No. 36 on reply card



LIGHTWEIGHT MOTOR

New lightweight, high-performance induction motors are said to provide the lowest motor weight to power ratios in the aircraft field without sacrificing efficiency or power factor. The illustrated model weighs 4.8 lb and is rated 6½ hp at 24,000 rpm; it operates on a three-phase 208-volt, 400-cycle current. Design features include totally enclosed explosion-proof construction, air or liquid cooling, and precision ball bearings. Models are available for power outputs from 10 watts to 1,000 hp.—Electromotive Div. of Task Corp., Anaheim, Calif.

Circle No. 37 on reply card

COMPONENT PARTS

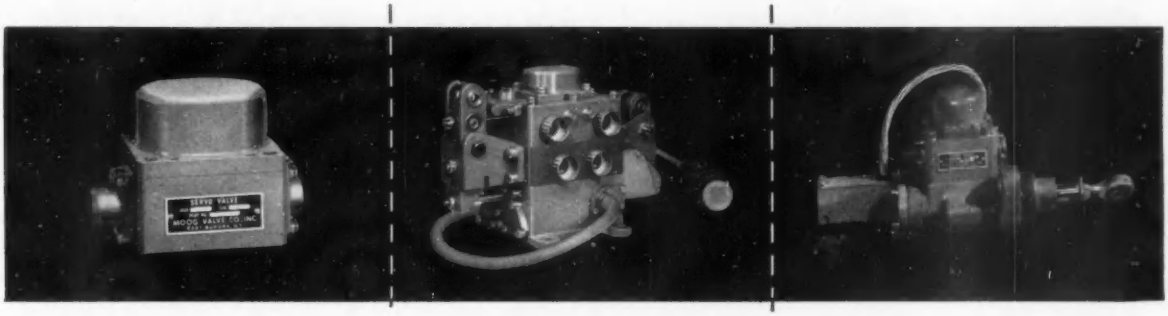
PERFORM AT 200 DEG C

Miniature metallized teflon capacitors give excellent performance at 200 deg C without derating. Developed under an Air-Force-sponsored research and development program, these capacitors feature a self-healing property, which has enabled them to un-

From MOOG . . . **Advanced Electro-Hydraulic Servo Components**

Moog is the industry's leading producer of electro-hydraulic servo valves. This leadership has been achieved by advanced valve design resulting in high performance, high quality, reliability and efficient manufacture. The same creative approach applied to industry's newer problems has resulted in the introduction of Moog Dual Input and Servo Actuator units.

These recent achievements in the creation of advanced custom designed electro-hydraulic servo components are evidence of Moog's continuing progress.



SERVO VALVE

• These proportional "dry motor" electro-hydraulic servo valves feature high dynamic response, sensitivity, linearity and reliability. Light-weight and compact, they are also available in custom designed versions for special or advanced applications.

DUAL INPUT SERVO VALVE

• This new component provides for positioning of aircraft control surfaces by summing mechanical and electrical inputs without external use of mechanical linkages. Use of an entirely new concept offers improved performance, system simplification and saving of space and weight.

SERVO ACTUATOR UNIT

• Custom designed integrated assemblies include actuating cylinder, electro-hydraulic servo valve and feedback sensing device. In a closed loop, actuator displacement is a function of input signal.

TO THE ENGINEER IN A "HURRY"

Axiomatically, to get somewhere in a hurry, you get aboard something that moves pretty fast.

If your "somewhere" is a career in engineering, consider Moog. From three founders to five hundred employees within five years, we are today the industry's leading manufacturer of advanced electro-hydraulic servo components. Our engineers made this possible by continuous pioneering of the new and successful developments in the field. As our rapid expansion continues, we have many openings at all levels for qualified personnel.

Best time to get aboard is now.

MOOG

MOOG VALVE CO., INC. PRONER AIRPORT, EAST AURORA, NEW YORK

Research Laboratory, Paramus, New Jersey

You get EXACTLY

what you set —

No More — No Less!



When you use NIAGARA

Displacement Meters for process control

Consistent accuracy in liquid measurements is obtained with Niagara Electricontact Meters. Set the gauge for the number of gallons required and accuracy goes into action. The set number of gallons will be exactly measured through the meter and the flow stopped by the closing of a solenoid valve.

Niagara Meters are of the accurate, positive displacement type. Each Niagara Meter is guaranteed to be individually tested and calibrated at the factory to run within close tolerances at all rates of flow within its rated capacity.

Learn all the facts . . . Mail the coupon for complete information.

Please send me complete information on the use of Niagara Electricontact Meters for liquid formulations.

Liquid used.....

Flow G.P.M.....°F.....

Name.....

Company.....

Address.....

BUFFALO METER CO.

2932 Main Street
BUFFALO 14, N. Y.

NEW PRODUCTS

dergo 1,000-hour load-life tests at 200 deg C and 140 percent rated voltage with no performance deterioration. Over repeated temperature cyclings from minus 55 to plus 200 deg C. capacitance change has been within 1 percent. Units are hermetically sealed in metal cans.—Balco Research Laboratories, Newark, N. J.

Circle No. 38 on reply card



DEMODULATOR

This is the ED-551 Phase-Sensitive Demodulator, which compares an ac input signal to a fixed reference. Variation in phase and amplitude between the input and reference is directly reflected in a dc output voltage. Good linearity and drift stability suit the unit for laboratory use as well as field applications. It is available with either an octal plug header or with solder-type terminals.—Atlas Electro-Mechanical Laboratories, Inc., Panorama City, Calif.

Circle No. 39 on reply card

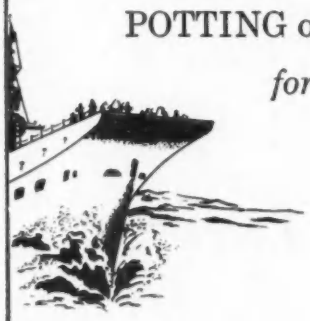


DC AMPLIFIER

Operating from a 60-cycle, 115-volt line, this new magnetic amplifier, featuring a linear, reversible output, can be used with thermocouples, strain gages, photoelectric cells, demodulators, and instrument pickoffs. Having an infinite internal gain, the unit is

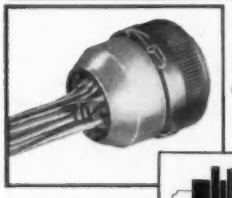
NEWEST METHOD OF SEALING AGAINST MOISTURE

POTTING of Cannon Connectors

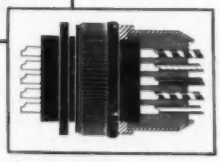


for...

1. ***Positive sealing*** against moisture, dirt, and other foreign matter.
2. ***Weight saving*** because of elimination of end bell and cable clamp.
3. ***Space saving*** due to shorter overall length.
4. ***Prevention of wire fatigue*** under extreme vibration.
5. ***Improved dielectric characteristics.***



Typical completed potted connector



Individual wires and elements are thoroughly sealed

CANNON offers these Connectors for Potting

CAO6BS Plug • Plastic Inserts 12S to 48 Sizes
CAO6BR Plug • Plastic Inserts 12S to 48 Sizes
CAO6ES Plug • Resilient Inserts 8S to 36 Sizes
CAO6ER Plug • Resilient Inserts 8S to 36 Sizes
CA3106BS Plug • Plastic Inserts 12S to 48 Sizes*
CA3106BR Plug • Plastic Inserts 12S to 48 Sizes*
CA3106ES Plug • Resilient Inserts 8S to 36 Sizes*
CA3106ER Plug • Resilient Inserts 8S to 36 Sizes*

**less grounding means*

Receptacles also available for potting.

Plugs and receptacles available with either pin or socket assemblies.

Please Note: Many other connectors may be potted by devising proper potting techniques.

CANNON Potting Molds



Nylon potting cup



Aluminum end bell

How It's Done...

Potting is a newly developed method of obtaining complete protection, covering, and sealing around the solder cups and wires at the rear of electric connectors by means of a sealing compound applied at the time the connectors are wired into their assemblies. The terminal area enclosed by the plug or receptacle end bell is filled or potted with a free flowing high solids synthetic rubber compound. This cures at room temperature to form a firm, resilient, moisture and vibration resistant rubber seal.

Clean the Connector...

The connector should be free of grease, oil and wax in order to insure good adhesion. Do not expose insulating materials to the cleaning solvent beyond the time necessary for adequate cleaning. *See the new Cannon Manual on Potting for complete information.*

Mixing the Compound...

Compounds are usually furnished as a basic sealant compound and an accelerator. Mixing must be done carefully, either by hand or with power equipment. *This subject is covered fully in new Cannon Manual on Potting.*

Applying the Sealant...

Application of the sealant can be made with a small paddle-shaped tool, spatula, putty knife or a flow gun. However, the flow gun is the preferred method where larger quantities of the plugs are to be sealed. *Methods are discussed fully in the new Cannon Manual on Potting.*

Potting Machines...

Large quantity runs can be handled economically by potting machines. Typical equipment of this nature is illustrated here.



Potting machine in use

Potting by hand



Curing Time...

Curing time and the methods used are very important. The length of time that it takes for the sealant to harden and cure varies with the material used. Generally, the length of cure time depends upon the work life of the compound. A longer work life increases and short work life decreases the cure period. *See the new Cannon Potting Manual for complete details.*

MIL-S-8516 (Aer) is basic specification on sealing compounds for electric connectors and electric systems. BuAer Bulletin Aer-EL-35 covers electric connector sealing to prevent contamination, improve reliability.

Cannon's engineering experience is available to you on your potting problems. Write TODAY for assistance and for new 12 page, 2-color, Potting Manual No. PM-1.



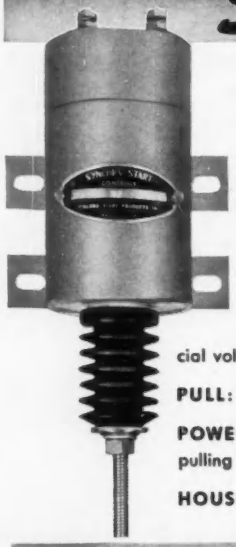
CANNON ELECTRIC

Please mention this magazine or Dept. 422

CANNON PLUGS

CANNON ELECTRIC CO., 3209 Humboldt St., Los Angeles 31, California. Factories in Los Angeles; East Haven; Toronto, Canada; London, England; Melbourne, Australia. Manufacturing licensees in Paris, France; Tokyo, Japan. Representatives in all principal cities.

HEAVY DUTY DC Solenoids



Synchro-Start MODEL SD SOLENOID has been developed to meet heavy duty requirements. It has an exceptional amount of power over a long stroke. The SD Solenoid is fully enclosed in a sealed case protecting it from infiltration of dust and liquids.

VOLTAGE: SD Solenoids can be furnished in all standard and special voltages up to 115 Volts D.C.

PULL: 10 lbs. over 1½ inch stroke.

POWER CONSUMPTION: 550 Watts pulling and 8 Watts holding.

HOUSING DIMENSIONS: 4⅝" x 2½".

SYNCHRO-START PRODUCTS
INCORPORATED
8151 N. RIDGEWAY AVE. • SKOKIE, ILL.

RdF STIKON®

RESISTANCE THERMOMETER ELEMENTS

ANSWERING INDUSTRY'S NEED FOR A *BETTER* WAY TO MEASURE SURFACE TEMPERATURES

Flexible • Easy To Apply
Low Cost • Fast Response



ACTUAL SIZE

RdF STIKONS bond readily to practically any surface.

Designed for research and manufacture in all fields of temperature measurement and control, high-output RdF STIKONS respond to changing temperatures in milliseconds and with remarkable accuracy. The thinness of the RdF STIKON (.005" to .010") opens up applications difficult or impossible with ordinary thermal sensing elements. Virtually a part of the surface to which it is applied, this miniature thermometer measures precisely any ABSOLUTE temperature within its range. Used in an appropriate bridge circuit, an RdF STIKON may easily produce output voltages several hundred times higher than the output of the most sensitive thermocouples.

SEND FOR T-56 BROCHURE OR WRITE DESCRIBING YOUR SPECIAL MEASUREMENT PROBLEM. IN ADDITION TO STANDARD RdF STIKONS, WE MANUFACTURE A WIDE VARIETY OF SPECIAL ELEMENTS AND SYSTEMS FOR TEMPERATURE MEASUREMENT AND CONTROL.

ARTHUR C. RUGE ASSOCIATES, INC.
733 CONCORD AVENUE CAMBRIDGE 38, MASSACHUSETTS

stabilized by current or voltage negative feedback external to it. The feedback parameters determine the amplifier's overall gain, which may be varied over a wide range. Zero drift is less than 0.2 percent of full-scale output for temperatures between 0 to 170 deg. F. Fluctuations of 10 percent in supply power voltage and frequency give a zero error of less than 1 percent full-scale output. Unit measures 2⅜ by 2¾ by 3¾ in. with plug-in terminals and four tie-down studs.–Dynamics Research Associates, Ferguson, Mo.

Circle No. 40 on reply card



3-MIN ACCURACY

Shown is one of a new series of size-23 synchros. These new units meet all performance requirements and provide at least twice the accuracy specified in the applicable military specs. They enable designers to increase the accuracy of their control and data transmission systems and servomechanisms. In many instances, a 3-min synchro eliminates the need for two-speed synchro systems, thereby reducing cost and effecting savings in weight and size. Matched pairs of synchros are available to provide even greater system accuracy.–Norden-Ketay Corp., Stamford, Conn.

Circle No. 41 on reply card

SHIFT REGISTERS

Single-line magnetic shift registers are now available which require only one shift pulse generator, use one magnetic core and one germanium diode per stage with vacuum tube driver, or one magnetic core and one transistor per

Three voltage ranges:
0-200, 125-325, 325-525 VDC

1.5 AMPERE MODELS **NEED ONLY 8¾" OF PANEL HEIGHT!**

(metered)		(unmetered)	
MODEL C-1580M:	0-200 VDC, 0-1500 MA....580.00	MODEL C-1580:	0-200 VDC, 0-1500 MA....550.00
MODEL C-1581M:	125-325 VDC, 0-1500 MA....605.00	MODEL C-1581:	125-325 VDC, 0-1500 MA....575.00
MODEL C-1582M:	325-525 VDC, 0-1500 MA....680.00	MODEL C-1582:	325-525 VDC, 0-1500 MA....650.00



800 MA MODELS **NEED ONLY 7" OF PANEL HEIGHT!**

(metered)		(unmetered)	
MODEL C-800M:	0-200 VDC, 0-800 MA....370.00	MODEL C-800:	0-200 VDC, 0-800 MA....340.00
MODEL C-801M:	125-325 VDC, 0-800 MA....345.00	MODEL C-801:	125-325 VDC, 0-800 MA....315.00
MODEL C-802M:	325-525 VDC, 0-800 MA....390.00	MODEL C-802:	325-525 VDC, 0-800 MA....360.00



400 MA MODELS **NEED ONLY 5¼" OF PANEL HEIGHT!**

(metered)		(unmetered)	
MODEL C-480M:	0-200 VDC, 0-400 MA....289.50	MODEL C-480:	0-200 VDC, 0-400 MA....259.50
MODEL C-481M:	125-325 VDC, 0-400 MA....274.50	MODEL C-481:	125-325 VDC, 0-400 MA....244.50
MODEL C-482M:	325-525 VDC, 0-400 MA....289.50	MODEL C-482:	325-525 VDC, 0-400 MA....259.50



200 MA MODELS **NEED ONLY 5¼" OF PANEL HEIGHT!**

(metered)		(unmetered)	
MODEL C-280M:	0-200 VDC, 0-200 MA....214.50	MODEL C-280:	0-200 VDC, 0-200 MA....184.50
MODEL C-281M:	125-325 VDC, 0-200 MA....189.50	MODEL C-281:	125-325 VDC, 0-200 MA....159.50
MODEL C-282M:	325-525 VDC, 0-200 MA....199.50	MODEL C-282:	325-525 VDC, 0-200 MA....169.50



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LOAD REGULATION ..... Better than 0.25% or 0.5 Volt, whichever is greater.

INTERNAL IMPEDANCE

C- 200 Series ..... Less than 6 ohms.
C- 400 Series ..... Less than 3 ohms.
C- 800 Series ..... Less than 1.5 ohms.
C-1500 Series ..... Less than 0.75 ohms.

RIPPLE AND NOISE..... Less than 3 millivolts rms.

POLARITY ..... Either positive or negative may be grounded.

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AC OUTPUT
(unregulated) ..... 6.5 VAC (at 115 VAC Input).

C- 200 Series ..... 10 AMP
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C- 800 Series ..... 20 AMP
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AC INPUT ..... 105-125 VAC, 50-400 CPS

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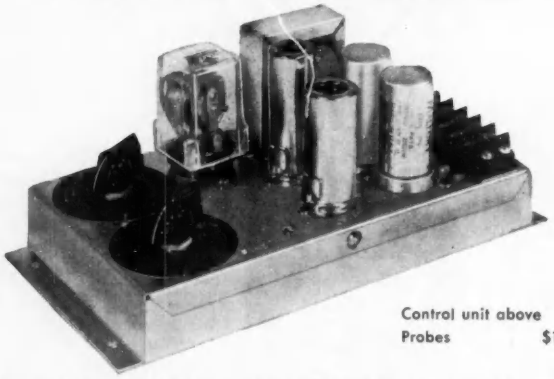
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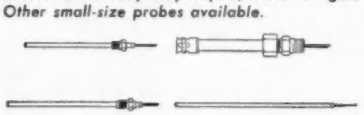


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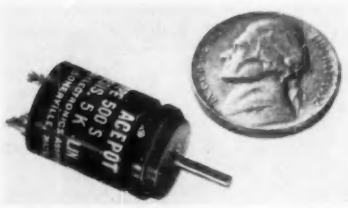
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NEW PRODUCTS

stage with transistor driver, and have operating frequencies from 0 to 10 kc, 50 kc, 100 kc, 250 kc, and 500 kc. Applications include buffer storage in input-output equipment, serial and/or parallel shift registers, data and program storage, and timing and counting circuits. Units have demonstrated life expectancies in excess of 40,000 hours. —Mack Electronics Div. of Mack Trucks, Inc., Boston, Mass.

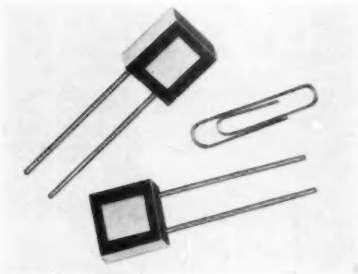
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LOW-TORQUE POT

This new jewel-bearing, subminiature, precision wire-wound potentiometer is designed for applications requiring minimum starting and running torque. It is not only highly accurate and small, says the manufacturer, but also is very rugged and will stand up under rough conditions. Features include a resistance range of 10 to 250 k ohms, linearity within plus or minus 0.3 percent, a power rating of 2 watts for 60-deg-C rise, and a torque of 0.01 oz-in. Size is ½ by ½ in. and weight is ¼ oz (including lockwasher and nut).—Ace Electronics Associates, Inc., Somerville, Mass.

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NEW PHOTOCELL

This new photocell is said to have more power controlling ability and sensitivity than any other on the market today. It is designed primarily for the direct operation of ac or dc relays, but will also operate electronic trigger

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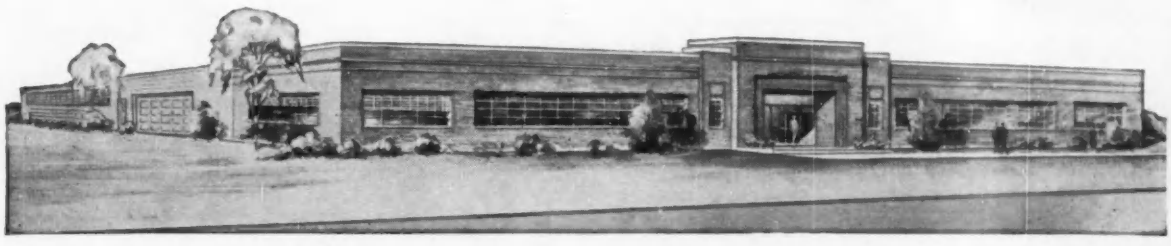


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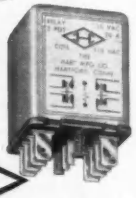
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High Capacity
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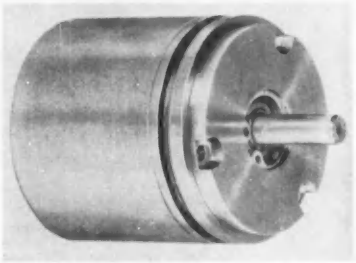
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NEW PRODUCTS

circuit at 1,000 counts per second. Continuous power dissipation of ½ watt, with short interval higher peaks, is said to be practical. Rating is 120 volts ac or dc. Total encapsulation in resin makes it moisture-proof and shock-proof. The unit operates as a nonpolar variable resistor, and the lowest sensitivity unit will pass 10 ma at 22.5 volts at 50 ft-candles. Dark resistance is over 1 megohm. It is most sensitive to blue-green light at 5,100 angstroms, although cadmium sulfide as used here gives a useful response to violet and red-orange light.—Hupp Electronics Co., Forest Park, Ill.

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TINY GEAR BOXES

A series of precision, miniaturized gear boxes for electronic and instrument applications, servomechanisms, computers, and small actuators are available in sizes 11, 15, and 18. These compact units have a wide range of gear ratios, from 4:1 to 12,000:1. They provide torques of 45, 65, and 100 oz-in. Ball bearings are used throughout with permanently lubricated bearings on the output stage. Largest unit is only 1.75 in. in diam and 1.9 in. long.—Southwestern Industries, Inc., Los Angeles, Calif.

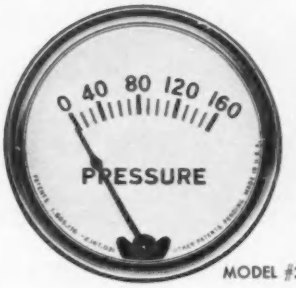
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RMC pressure gauges are capable of withstanding very high overload pressure above a nominal scale reading. Various types are available in different models, sizes, etc. All are built for use on heavy-duty equipment, to maintain accurate readings regardless of mechanical vibration, or exposure to dust and weather.

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RMC's general line of industrial thermometers cover just about every possible application. All are of stainless steel construction, with hermetically sealed dials. They are factory calibrated and pressure tested. External dial reset device permits on-the-job calibration for pin-point accuracy.



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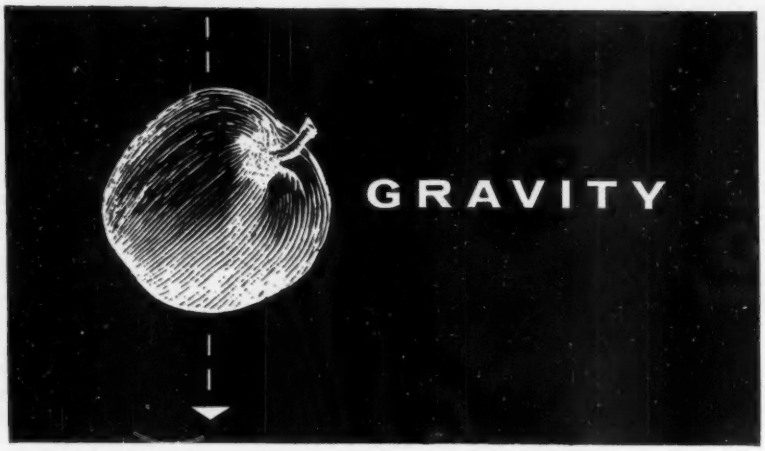
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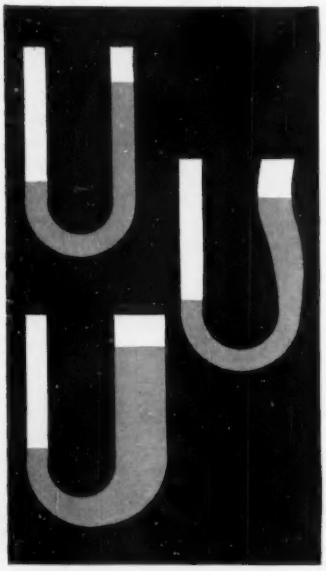
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ings. Mounting designs include servo, three-hole with central pilot, or threaded bushing.—DeJur-Amsco Corp., Long Island City, N. Y.

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FOR SOLDERLESS WIRING

A new terminal-block design features a precision-reamed tapered receptical to accommodate solderless connections. Positive locking between the taper pin and molded-in receptacle is assured. Any pair or combination of shorted contacts may be ordered. Taper receptacles are gold-plated brass over silver for low-contact resistance. Bodies are molded of high-impact, reinforced, glass-filled Alkyd, type 440A.—Electronics Sales Div., DeJUR-Amsco Corp., Long Island City, N. Y.

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"GAGE SAVER"

This unit provides a positive automatic protection against gage overload in hydraulic, fuel, or pneumatic systems. System pressure above its maximum operating limit automatically shuts off the gage; pressure drop to within limits reconnects it. A compression spring controls the shutoff point and may be adjusted to accommodate minor changes. Standard units with ¼-in. male-tube inlet connection and ¼ in. male-tube or ¼ in. female-tube outlet connection are available from stock. All shutoff pressures are from 60 to 3,000 psi.—Fisher Controls, Inc., Santa Monica, Calif.

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(100) MOTOR-GEARHEAD. Servomechanisms, Inc. Data Sheet, 1 pp. Describes a new miniature motor-gearhead-clutch, BuOrd size 10. Gives preliminary information on both electrical and mechanical characteristics. Also includes a dimensioned drawing and a connection diagram.

(101) INDUSTRIAL CONTROLS. Minneapolis-Honeywell Regulator Co., Industrial Div. Catalog 6f/MI, 12 pp. Covers a line of industrial controls for temperature, pressure, and humidity, with other sections on flame safeguard systems, industrial motors, and relays. Relays are of the pneumatic, electric, and combination types.

(102) MINIATURE BEARINGS. Landis & Gyr, Inc. Catalog, 16 pp. Lists all of the miniature ball and roller bearings in the company's RMB line, giving drawings, full descriptions, dimension tables, and mounting information. Also covers a number of inch-dimensioned open and sealed radial bearings in ABEC Class 1 tolerances as well as ABEC Class 5.

(103) METAL DETECTOR. E. W. Brilmayer Laboratories, Inc. Brochure, 4 pp. Describes a new electronic metal detector that can be custom-built to suit production problems. Has one section devoted to the application of the detector in the bread-baking industry. A dimensioned drawing of the coil unit is also included.

(104) RESEARCH FACILITIES. Armour Research Foundation of Illinois Institute of Technology. Brochure containing five four-page folders explains the type of research being conducted in the following technical areas: control systems; electronic instrumentation; electric machines, components, and measurements; computer systems; communications, and radio frequency applications.

(105) SERVO MOTORS. Norden-Ketay Corp. Bulletin No. 385, 8 pp. Offers engineers complete information on standard and custom servomotors. Data include electrical and mechanical specifications, application data on direct plate-to-plate, transistorized servo-amplifier and magnetic servo-amplifier applications. Briefly covers motor tachometers, tach-generators, and gearhead servomotors.

(106) LOAD & FREQUENCY CONTROL. Minneapolis-Honeywell Regulator Co., Industrial Div. Bulletin B91-1, 24 pp. Describes all-electronic load and frequency control systems for captive plant, small utilities, and multiple-station systems. Covers the individual servos that form an interlocking, continuous chain for the cumulative control of all factors, from ties to generators.

(107) CHECK VALVES. Aircraft Products Co. Series 1800 Data Sheet, 2 pp. Sheet describes the first MS-approved aluminum alloy check valve, and a complete line of MS-type lightweight check valves for 3,000-psi service. Basic materials used, rated flow capacities, dimensions, and weights are presented in tabular form.

(108) LIQUID FILTER. Air-Maze Corp. Catalog LFC, 16 pp. Gives complete data for designers and users of equipment requiring full-flow filtration of lubricating, hydraulic, or fuel oils. Data include gpm ratings, pressure drops, inlet and outlet sizes, weights, overall dimensions, and required clearances for cartridge removal.

(109) MOTOR SELECTION. Century Electric Co. Application Guide No. 102, 12 pp. Simplifies the selection of motors for all popular applications. Tabulates the following: typical driven equipment, character of the load, type and description of the motor to be used, starting current,

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speed range, hp range, and available enclosures.

(110) AIR & VACUUM PUMPS. Leiman Bros., Inc. Catalog No. 1957, 16 pp. Gives details of construction, dimensions, capacities, performance curves, and installation of a complete line of rotary positive displacement air and vacuum pumps, gas boosters, and air motors. Motor-driven, belt-driven, and direct-coupled units are covered, along with automatically controlled tank units.

(111) OXYGEN ANALYZER. Consolidated Electrodynamics Corp. Bulletin CEC 1841, 2 pp. Contains a general description of the Type 38-301 Oxygen Analyzer, and gives a number of process-plant applications. The principle of operation is briefly described and a schematic diagram shows the operating cycle.

(112) CONTROL RELAYS. Assembly Products, Inc. Bulletin 104, 12 pp. Furnishes detailed information on a complete line of miniaturized relays for automatic control systems. Contains more than three pages on circuitry alone. Principles of operation, electrical and mechanical specifications, and prices are also included.

(113) DATA REDUCTION. Coleman Engineering Co., Inc. Bulletin No. CR-187. Describes, with the aid of a block diagram, the various combinations of accessories and output equipment which can be combined with this company's Oscillogram Reader in the building up of a customized data-reduction instrument to best suit the needs of the individual user.

(114) DISPLACEMENT FOLLOWER. Optron Corp. Brochure, 8 pp., and component specification sheets. Describes a device for measuring displacement, runout, or vibration of mechanical parts. Brochure contains diagrams and photos illustrating the captured-spot principle of operation and some typical applications. Sheets cover the mechanical and electrical specifications of the system components.

(115) TEST INSTRUMENTS. Shasta Div. of Beckman Instruments, Inc. Catalog S-57, 4 pp. Design features and a brief list of specifications are given here for each of ten test instruments. Photos accompany these descriptions. Instruments include: expanded-scale voltmeters, frequency meters, synchro testers, vacuum-tube voltmeters, oscillators, resistance bridges, power supplies, and wide-band amplifiers.

(116) PNEUMATIC CONTROLLERS. Minneapolis-Honeywell Regulator Co., Industrial Div. Catalog 600/700-1, 8 pp. Covers the Brown line of small-case indicating pneumatic controllers for temperature and pressure. These units have temperature ranges between 0 and 1,000 deg F, and pressure ranges between 0 and 1,000 psi. Individual specifications as well as specifications common to both types are given.

(117) INDUSTRIAL DATA SYSTEMS. Beckman Instruments, Inc. Reprint R-98. Entitled "Increased Reliability of Industrial Data Systems", this paper was prepared by three research engineers connected with the Scientific Instruments Div. An adaptation of a paper given at the 11th annual ISA Conference, it traces the development of the industrial data system and forecasts its role in the future development of closed-loop automation systems. Reliability of electromechanical and electronic components is also discussed.

(118) ULTRAVIOLET ANALYZER. Consolidated Electrodynamics Corp. Bulletin 1842, 2 pp. Covers an ultraviolet analyzer designed for the continuous monitoring and control of petroleum, petrochemical, and allied processes. Points out the important features of the unit and lists both physical and electrical specifications. Two-color diagram illustrates the function of each component.

(119) THERMOSTATS. The Franklin Dales Co. Engineering Data Book, 8 pp. Illustrates a line of compact thermostats for use in cycling systems, fire-alarm and sprinkler systems, automatic making and breaking circuits, and regulating systems. Table gives dimensions and electrical ratings.

(120) DIGITAL COMPUTER. Computer Div., Bendix Aviation Corp. Bulletin AB116, 6 pp. Describes the Bendix G-15D general-purpose digital computer and its digital differential analyzer accessory. Covers programming advantages, lists specifications, and tabulates input and output accessories. Back cover suggests a wide variety of applications.

(121) FLAT-TYPE MOTORS. Diehl Mfg. Co. Bulletin No. 3461, 4 pp. Lists ratings on two totally-enclosed flat-tpye motors. Compares the size and weight of these new motors with the physical characteristics of standard-size units, showing how they obtain maximum power in minimum space.

(122) RADIATION SPECTROMETER. Mount Sopris Instrument Corp. Brochure, 4 pp. Lists applications and characteristics of a new radiation spectrometer. Gives the electrical specifications of these four components: linear pulse amplifier, Model PA-303; pulse height analyzer, Model PHA-304; ratemeter, Model R-302; and a variable high-voltage regulated power supply, Model PS-301.

(123) MOTION TRANSDUCER. Minneapolis-Honeywell Regulator Co., Industrial Div. Instrumentation Data Sheet 10.18-12, 2 pp. Explains how the Sotsman Linear Motion Transducer can be used with the Brown ElectroniK instrument wherever linear or angular motion must be measured with a high degree of reliability and accuracy. Typical applications, performance data, and construction features

are illustrated for linear and angular motion types.

(124) COMPUTING RELAY. Bailey Meter Co. Product Specification P99-3, 4 pp. Describes features, applications, and operating characteristics of a computing relay for pneumatic systems. Explains proportional, reset, and rate control actions, and provides equations of computing actions.

(125) "AUTOMATION". Bendix Aviation Corp. Booklet, 12 pp. This handy booklet is a reprint of an address given by Malcolm P. Ferguson, president of Bendix, at the Third International Management Conference. It discusses some of the exciting prospects in the field.

(126) GUIDANCE & CONTROL. Humphrey, Inc. Catalog, 24 pp. Contains photos, diagrams, descriptions, and test data on some 21 precision guidance and control instruments. Complete with table of contents, it covers free gyros, rate gyros, linear and angular accelerometers, and rectilinear and rotary potentiometers. One section describes the company's test procedures to assure quality performance of each instrument.

(127) POT PERFORMANCE. Helipot Corp. Technical Paper 762, 12 pp. Entitled "Environmental Effects on Precision Potentiometers", this paper discusses the effects of extreme temperatures, vibrations and shock, humidity, altitude, and acceleration on precision potentiometers. Paper was originally presented at the Western Electronics Convention.

(128) PHOTOCONDUCTORS. Electronics Corp. of America. Bulletin TR-101, 8 pp. This well-illustrated bulletin describes infrared-sensitive lead sulfide photoconductors for detection and guidance systems. Technical details and ordering information are given for four different cell types having a variety of characteristics. Charts for cell response as a function of both wave-length and source temperature are shown.

(129) ELECTRONIC COMPONENTS. Freed Transformer Co. Catalog 571, 48 pp. Covers a complete line of transformers, filters, discriminators, toroids, magnetic amplifiers, and ultrasonic components. Includes 128 graphs showing the performance of many of these units. Data on transformers for both military and commercial applications are also given.

(130) COMBUSTION CONTROL. General Controls Co. General Catalog. Covers everything required for a complete combustion installation: automatic draft-control instruments and actuators; solenoid, diaphragm, and motor-operated valves for oil, gas, steam and water; time switches, relays and oil burner primary controls, etc.

(131) FLOAT SWITCHES. Revere Corp. of America. Engineering Bulletin No. 1066, 2 pp. Describes two new float switches for indicating or controlling the level of liquid oxygen or liquid nitrogen in missiles, test facilities, and storage or transportation tanks. Features, dimensions and specifications are also included.

(132) ELECTRON TUBES. Industro, Inc., Bulletin A1-55-IOM, 22 pp. Just about 1,000 tubes, arranged according to type, description, code, and list price, are catalogued here.

PROBLEM #2



Design a miniaturized 400 cycle filament transformer for airborne operation. Transformer to operate in an ambient temperature ranging from —55° C to +100° C. The maximum allowable temperature rise to be 60° over ambient. Dimensions cannot exceed 2-7/8" high, by 2-7/16" wide, by 2-1/2" long, nor can the weight exceed 2 pounds. The primary source to be 115V, with primary insulation for 500V RMS hipot. An electrostatic shield is required between the primary and secondary. The secondary is required to deliver 10 amperes at 5V (C.T.), ±3%, have a total maximum capacitance of 60 micromicrofarads to other windings, shield and core, and be able to stand a high potential test of 21,000V, RMS, @ 60 cycles. Construction to be in accordance with applicable parts of MIL-T-27, Grade 2, Class B. The above are given as maximum dimension and minimum performance requirements, greatest possible improvement in size, weight and performance requested.

SOLUTION BY PEERLESS

Filament transformer, Fosterite impregnated	
Primary:	115V, 380 to 1600 cps Hipot at 1000V, RMS, 60 cps
Electrostatic shield grounded to core.	
Secondary:	5V, C.T., ±1/4% @ 10 amp. Hipot at 25,000V, RMS, 60 cps for one minute Distributed capacitance to other winding, shield and core: 50 micromicrofarads.
Temperature Rise:	30° C
Ambient temperature range:	—55° C to +100° C
Weight:	12 ounces
Dimensions:	H: 2-1/4" + 3/8" terminal W: 2-3/16" L: 2-1/2"

The Peerless engineering staff has had a long and successful history of designing transformers to unusual and difficult specifications. Knowledge of this outstanding accomplishment is one of the reasons that Peerless transformers are the first choice of engineers throughout the country. Uniform dependability is assured by the most rigid quality control and advanced custom production techniques.

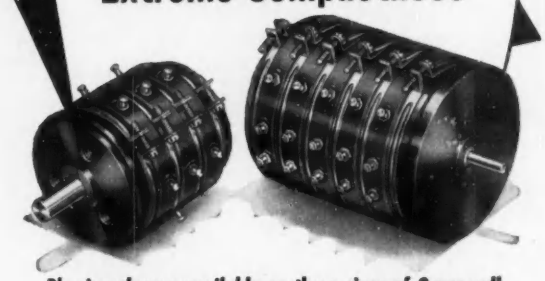
Consult Peerless for the best solution to your quality transformer requirements.

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More information, prices and delivery available from Gamewell representatives or write:

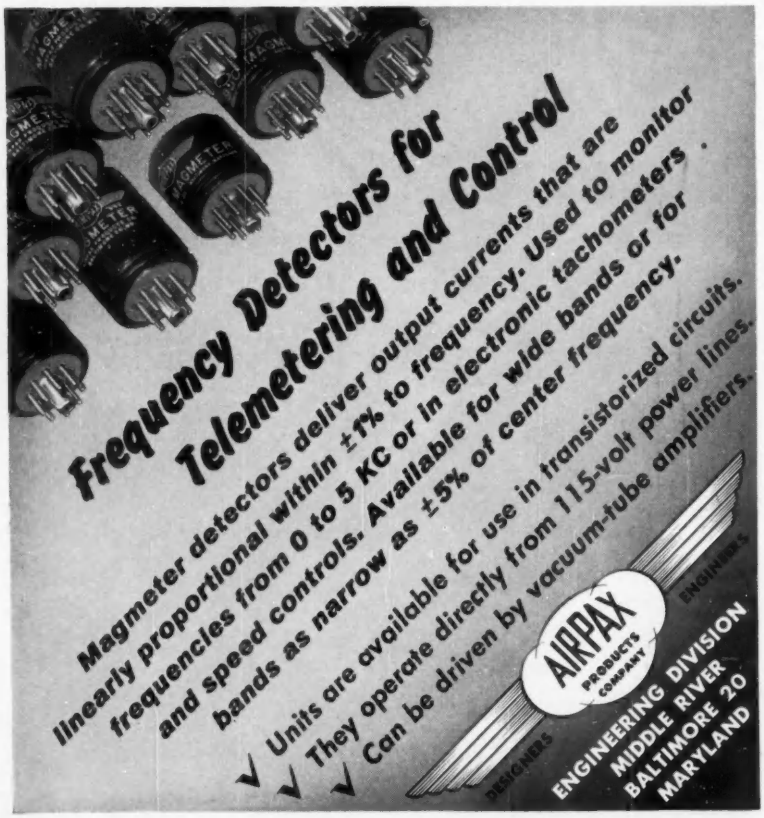
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APPLICATION LITERATURE

NOTE: Because some of the items below are "priced," we have omitted card numbers and suggest that interested readers write directly to the companies involved.

"TRANSISTOR MANUAL". Semiconductor Products Dept., General Electric Co., Syracuse, N. Y. This 62-page booklet is designed to assist service technicians and design engineers in working with transis-



tors. It includes sections on basic semiconductor theory, techniques for manufacturing transistors, applications, circuit designs, and specifications. There are also complete explanations of common transistor parameter symbols, 19 typical circuit diagrams, a complete parts list, and a four-page table of registered RETMA transistor types. Inside back cover contains a short suggested reading list. Price: 50 cents.

INSTRUMENT TECHNIQUES. Barnes Engineering Co., 30 Commerce Rd., Stam-



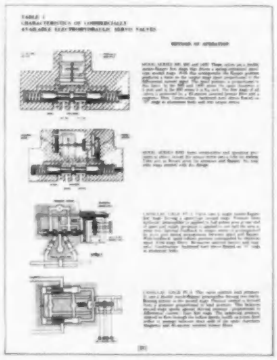
An application of the OptiTherm 4" Radiometer

Measuring the radiation from the clear sky

ford, Conn. Entitled "Techniques", this periodical contains a number of interesting articles on both laboratory and industrial

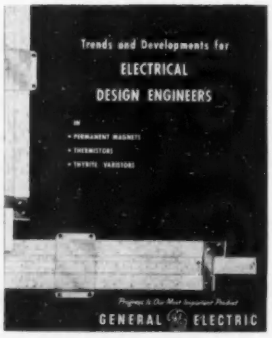
instrumentation. The Winter 1957 edition, for example, carries an article on measuring the intensity of radiation from the sky as a function of sun altitude, humidity, time of year, etc. A second article describes a simple method of calibrating a radiometer using a small black-body source.

ELECTROHYDRAULIC SERVO VALVES. Cook Research Laboratories, Cook Electric Co., 2700 N. Southport Ave., Chicago 14, Ill. Volume 3, Number 2 of "The Cook Technical Review" consists of a 25-page article entitled "Electrohydraulic Servo Valves", the first part of which

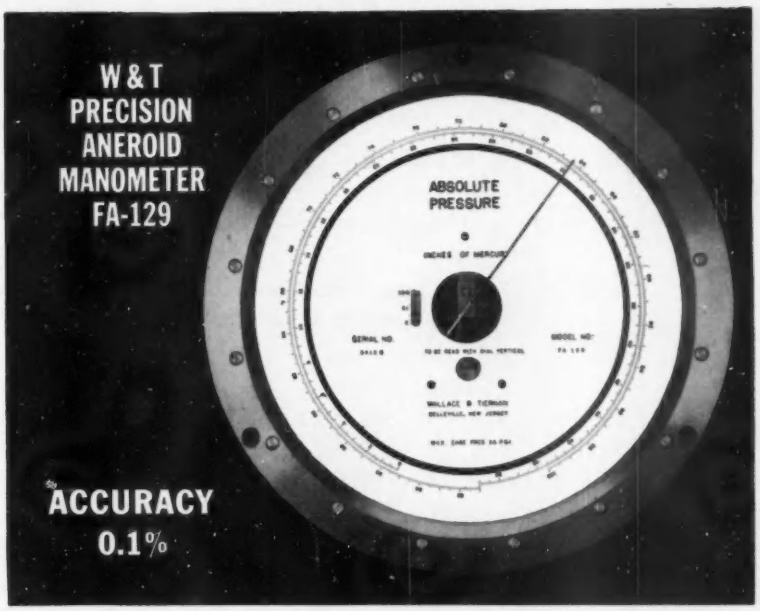


". . . is intended to provide the system designer and analyst with basic information relative to the types and characteristics of high response servo control valves". The second part discusses applications and a number of design considerations. Table 1 (above), describes the characteristics and mode of operation of four commercially available valves. Price: $1.

TRENDS IN DESIGN. Magnetic Materials Section, General Electric Co., Edmore, Mich. "Trends and Developments for Electrical Design Engineers" a new 12-page booklet, is divided into four sections covering permanent magnets, thermistors, and Thyrite varistors. First section de-



scribes the role of permanent magnets in miniaturization and tells how to determine the proper grade of magnet for a particular application and how to magnetize pm's to obtain maximum energy product and magnetic stability. Magnetic and physical properties of Alnico magnets, along with demagnetization and energy product curves, are covered in the second section, Thyrite varistors in the third and fourth.



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Accuracy:	1/1000 of full scale
Sensitivity:	1/10,000 in *all* ranges
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Write for Publication No. TP-15-A

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Write for Bulletin No. M-32

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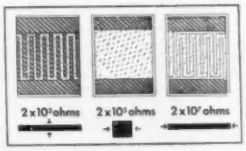
M-32

This is a photosensitive resistor... actual size



It's called a Kodak Ektron Detector, the photosensitive substance is lead sulfide, and it can be laid down in any pattern.

- Signal response extends from 0.25 microns in the ultraviolet to 3.5 microns in the infrared with maximum sensitivity at 2.2 microns in the infrared.
- They are available in complex and exact arrays and mosaics.



- Signal-to-noise ratio is excellent, particularly in the infrared.
- Vibration doesn't affect them.
- Elements can be extremely small in size.

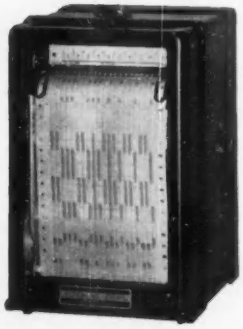
To get the details on Kodak Ektron Detectors, write for a free booklet to: Military and Special Products Sales,

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Kodak
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ARE THESE PROBLEMS BOTHERING YOU?

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- **Flow of materials?**
- **Position of gates and dampers?**
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- **Sequence of switching?**
- **Timing of events?**



The operation recorder will obtain the answers to these problems, and many more, for you. An instrument with 20 pens writing on a moving chart, the operation recorder shows:

- *When events occur*
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WHAT'S NEW

(Continued from page 54)

display techniques, particularly those connected with aircraft instrumentation, image pickup equipment, and data and image storage and reproduction. Deichert, formerly head of the Circuit Research Div., where the new department will be located, joined Du Mont in 1951 after several years as an instructor in electrical engineering at Pratt Institute and Stevens Institute. He still serves Stevens as a visiting lecturer in the graduate school.

Taft-Peirce Mfg. Co. of Woonsocket, R. I., whose Instrument Gage Div. will be managed by Franklin Meyer Jr., formerly chief engineer for instrument gages. A contemplated expansion of development and production facilities for air and electronic air gaging is in back of the move, which caps Taft-Peirce's steadily growing emphasis on these devices.

▶New companies are also making news. Among them:

Systron Corp. of Concord, Calif., which will design and build electronic control systems and data processing equipment for industry, putting greatest stress on automation processes for industrial plants. President and director is G. H. Burns Jr., who continues as a director of **Donner Scientific Co.** He formerly was general manager of the Berkeley Div. of **Beckman Instruments, Inc.**

Also in California: **Kelvin Electric Co.** of Van Nuys, which will specialize in precision wire-wound resistors for industrial and military electronic equipment, and in resistive networks for use as attenuators and precision voltage dividers. Heading the new concern are William I. Elliott and Kenneth T. Eckardt, formerly president and vice-president, respectively, of **Hycor Co., Inc.**

In Chicago: **Electronic Systems of Illinois, Inc.**, whose leading lights are Thomas N. McGowan, financial consultant, and Theodore W. Batterman and Mathew Pobog, who are, respectively, president, and vice-president and chief engineer. Electronic control devices immediately scheduled include an automatic shutter control for printing motion-picture film, and a simplified and miniaturized photoelectric relay system which uses neither tubes nor transistors.

In Cleveland: **General Servo Motors, Inc.**, which specializes in the application of high-frequency, rapid-response, electrohydraulic servo valves, principally in airplane and rocket-flight control. Among its current projects:

Activities at Lockheed Missile Systems Division laboratories in Palo Alto cover virtually every field of electronics related to missile systems. Inquiries are invited from those who desire to perform research and development of a most advanced nature.

Here staff members discuss a laboratory model of an airborne component of a guidance system. Left to right: Dr. R. J. Burke, telemetering; S. Janken, product engineering; K. T. Larkin, reliability; E. A. Blasi, antennas; Dr. S. B. Batdorf, electronic division head; Dr. H. H. Leifer, solid state.

Lockheed

MISSILE SYSTEMS DIVISION

research and engineering staff

LOCKHEED AIRCRAFT CORPORATION

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a pressure controller for a rocket blowdown tunnel for **North American Aviation, Inc.**, and a jet-engine fuel-control research job.

And in Houston, Tex.: **C. L. Shultz & Associates,** consultants and control-system designers for the process industries. Officers are C. L. Shultz and Frank H. Sparks, both formerly with **Shell Oil Co.** at Houston.

IMPORTANT MOVES BY KEY PEOPLE

Shannon Goes to MIT as a Full-Time Professor

Educators, who have constantly been decrying their inability to compete with industrial anglers in the streams of technical talent, have finally landed one of the biggest fish. He is Claude E. Shannon, one of the world's leading scientists and the man who probably has done more to dramatize the importance of training in symbolic logic in the age of the computer than anyone else. Shannon leaves Bell Telephone Laboratories, where he has been a research mathematician, to join the faculty of MIT in the unique dual capacity of professor of communications sciences in the Dept. of Electrical Engineering and professor of mathematics.

Neither the halls of MIT nor the front of a classroom are new to Shannon. He became acquainted with the first back in the days when he worked for a master's degree in EE and a PhD in physics, with the second in the late 30's, when he served as a research assistant and an assistant in mathematics. For the past year he has been visiting professor of electrical communications at the Cambridge institute.

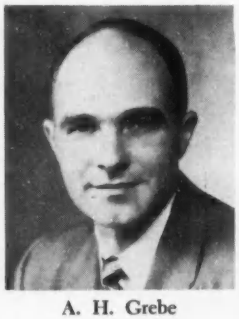
Shannon left MIT in 1940 for a year of work at the Institute of Advanced Study at Princeton, and in 1941 he joined Bell Labs. His contributions to information theory, which include theoretical studies of machines that will play chess and other games, have brought him the Alfred Noble Prize of the AIEE, the Morris Liebman Award of the IRE, the Stuart Ballantine Medal of the Franklin Institute, and, just recently, the 1956 Research Corporation Award. He is a member of the National Academy of Sciences.

Perhaps overshadowed news-wise by Shannon's acquisition, but actually of no less significance in the running of the institute, are a pair of top-level changes in MIT's Lincoln Laboratory. As a result of these changes, Carl F. J. Overhage succeeds Marshall G. Holloway as director, and William H. Radford replaces George E. Valley as assistant director.

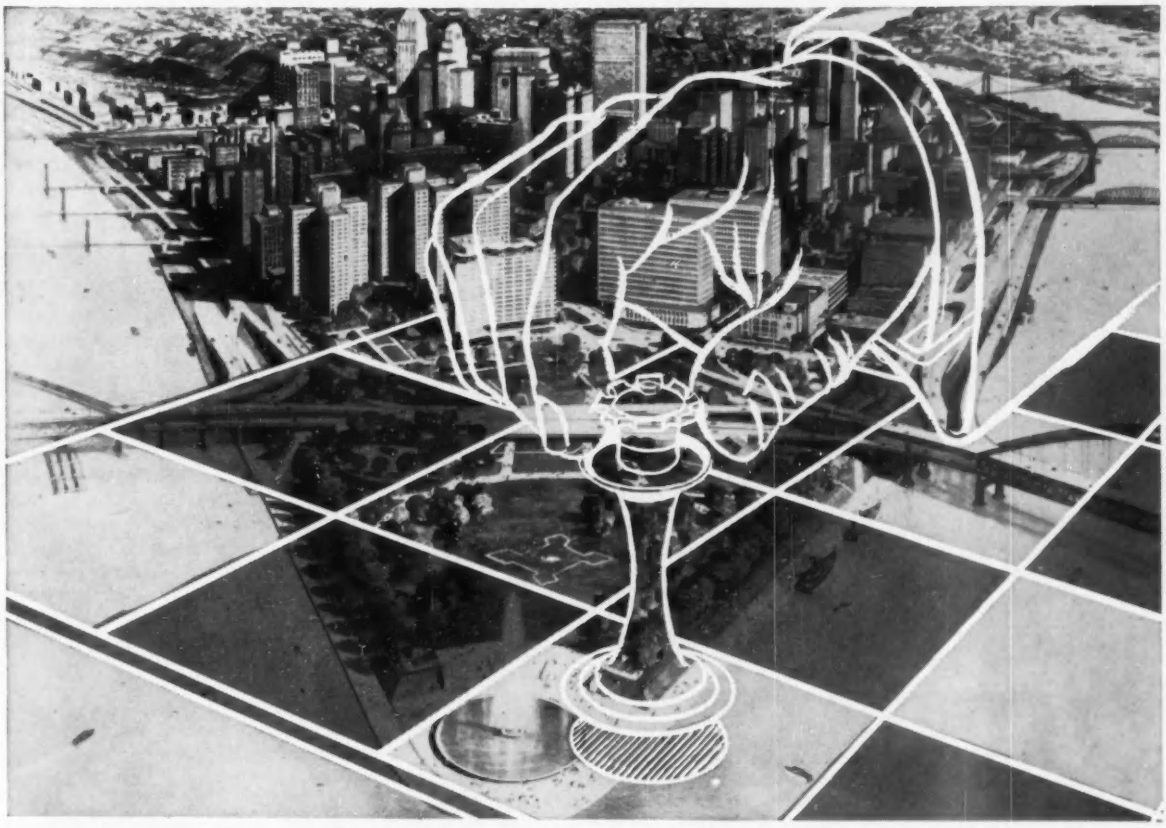
Overhage, most recently a division head at Lincoln, has been in and out of MIT since the war, when he served as a group leader at the Radiation Laboratory. Between times he was on the staff of Eastman Kodak Co. and a member of the Scientific Advisory Board of the Air Force. He is a fellow of the American Physical Society and a holder of the President's Certificate of Merit for his war work. Radford, who has been on MIT's electrical engineering faculty since 1932, became a full professor in 1951. He helped establish the institute's radar school in 1941 and was appointed an associate director of it in 1944. He joined the Lincoln Laboratory in 1953. He is a fellow of the IRE and of the American Association for the Advancement of Science.

Holloway was with the Los Alamos Scientific Laboratory in New Mexico before he took the helm of the Lincoln Laboratory in 1955. He leaves to go into industry. Valley, promoted


H. E. Pinkerton


A. H. Grebe


M. H. Murphy



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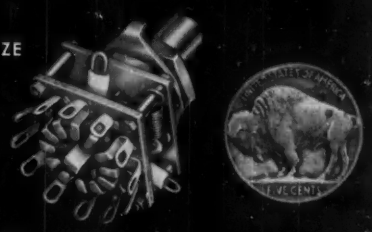
Responsible for materials and processes application to marine nuclear power plants.

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SUB-MINIATURE ROTARY MULTI-POLE, MULTI-DECK 12-position SWITCH M-12

ACTUAL SIZE



Features:

- ***Small Size*** — only ¾" square.
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WHAT'S NEW

from associate to full professor of physics, returns to faculty service on the campus at Cambridge.

Airborne Instruments Man Heads U.S.-French Concern

Intercontinental Electronics Corp., the unique U.S.-French manufacturing-marketing concern organized principally by Airborne Instruments Laboratory and Campagnie Generale de Telegraphie Sans Fil of France, has named an AIL executive as its president. He is Harry E. Pinkerton, manager of the company's Engineering Applications Div. and a guiding light behind such AIL developments as the new Inchworm motor (CTE, September '56, p. 40). The idea behind Intec is to market in the U.S. electronic devices developed in France. Acknowledging his responsibility to further this, Pinkerton said, "The broad expanding field of industrial and commercial electronics all lies ahead and can only be exploited through a devoted application of the best principles of international scientific fellowship. Intec's objective has been and will continue to be the furthering of this fellowship in every accessible industrial and commercial front."

Behind Pinkerton and his organization are the talents and reputations of five French and American firms: the two principal ones and these others: American Research & Development Corp., Banque de Paris et de Pays Bas of France, and J. P. Morgan Co. of New York.

Other Important Moves

► **Afred H. Grebe,** the new chief research and development engineer for Filtors, Inc., came to the company in 1953, when he discontinued his own business. His is the second R&D appointment to be made by Filtors in the space of about a month (CtE, March, p. 190).

► Packard-Bell Electronics Corp. has raised **Melvin H. Murphy** from assistant chief project engineer in the Technical Products Div. to chief electronic engineer in that division. He came to P-B from Brubaker Mfg. Co., where he steered the design and development of delay lines, pulse-forming networks, filters, and other electronic components.

► Three recent appointments by Tally Register Corp. spotlight **Robert A. Cole,** named chief engineer; **Stuart D. Barger,** named assistant chief engineer,

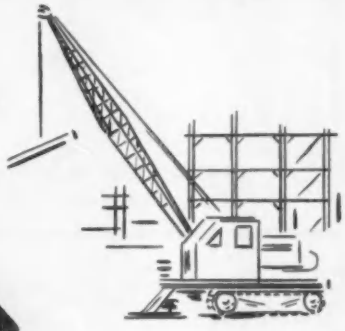
MISSILES to MACHINERY

Century MODEL 420 ELECTROGRAPH

covers the oscillograph recording field







TELEMETRY APPLICATIONS

- QUICK-LOOK monitoring in the telemetry ground station permits continuous observation of missile in-flight programing results.
- ON-THE-SPOT monitoring permits making in-flight function corrections in controlled missiles or piloted aircraft.
- A NATURAL for mobile telemetry vans . . . compact, rugged, low power consumption, record is PERMANENT, no fading or fogging when exposed to direct sunlight.

INDUSTRIAL APPLICATIONS

- STRESS-STRAIN RECORDING with "first-hand" read-out during test.
- PERMANENT record obtained at test site may be stored indefinitely for purpose of future data reduction.
- PORTABLE — extremely useful for field test applications where a "multiplicity" of data must be collected with the least amount of instrumentation.
- No amplifiers required for many applications.

USES a variety of tubular mirror galvanometers pioneered by Century

ENGINEERS . . .

Check your requirements against these FEATURES!

- Permanent continuous record produced within recorder.
- Developed record may be viewed an INSTANT after exposure.
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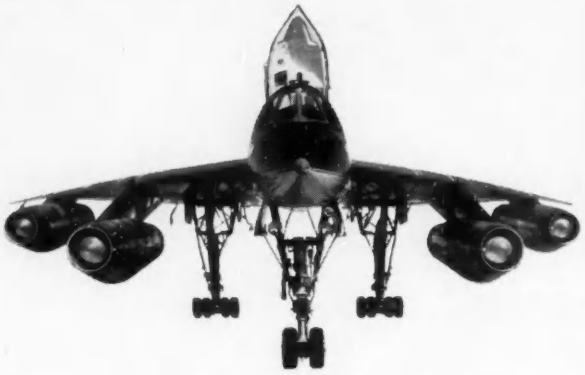
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Honeywell
Aeronautical Division

WHAT'S NEW

and **Tedrowe Watkins,** named supervisor of administrative services. Cole, who comes from Boeing Airplane Co., where he had been supervisor of computation and data processing, suc-



R. A. Cole



S. D. Barger

ceeds Vice-President **M. Ray Dilling,** who will devote more time to the sales end of the business. The new chief engineer is a "ground-floor" man in the missile field: his 15 years in it include wartime service at Wright Field, Dayton, as an R&D engineer in the special weapon section. Barger and Watkins step up from other positions in the company.

► Two new vice-presidents of the Convair Div. of General Dynamics Corp. have handsome backgrounds in electronics. They are: **B. F. Coggan,** who has been manager at San Diego since



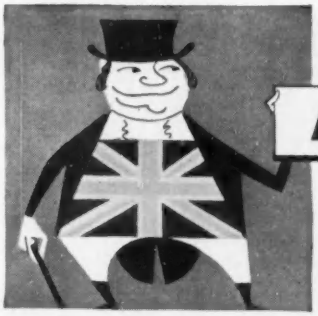
C. F. Horne



B. F. Coggan

1952, and **Charles F. Horne,** manager at Pomona, Calif., since 1953. Coggan directed missile and aircraft projects at General Motors' Fisher Body Div. before joining Convair; Horne, a retired rear admiral, got most of his experience in naval electronics.

► **Harvard L. Hull,** whose appointment as a vice-president of Litton Industries was belatedly reported last month (CtE, March, p. 192), has been named general manager of Litton Industries of Maryland, Inc., the College Park, Md., subsidiary formerly known as Ahrendt Instrument Co. Hull becomes the top resident executive at College Park, replacing **William R. Ahrendt,** founder of the subsidiary, who is on a leave of absence. Both moves (Hull's transfer and the change in name) are part of a Litton program to expand operations in the east.



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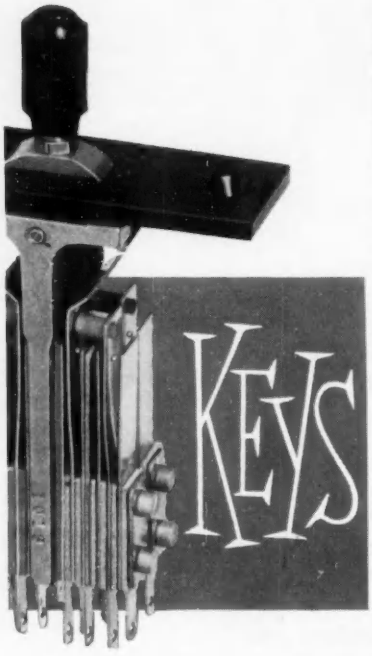
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WHAT'S NEW

Reactors Shun Feedback Control

(Continued from page 24)

cost of the plant. That puts the instrument investment in the $5-million EBWR over the million-dollar mark, even though Argonne engineers tried to use available components wherever possible.

EBWR instrumentation is divided into two parts: reactor system and power plant. All are brought out to a central control room.

Most of the nuclear instruments were supplied by Leeds & Northrup Co., the rest specially designed and built at Argonne.

Measurements necessary for nuclear control are indicated by L&N Speedomax recorders, which chart the signals fed to them from ionization chamber primary elements. Major items:

- Linear flux recorder. Strip chart instrument records the output of an electrometer at low reactor-power levels and the output of a micromicroammeter from intermediate to full power levels.
- Log period. The logarithm of the neutron flux is recorded and the period is indicated on a meter at the control console.
- Log flux. Output of the log amplifier is recorded on a strip chart by an instrument with a logarithmic scale calibration of 10^{-4} to 3×10^{2} and a 3-sec pen speed.
- Monitor record. Gamma radiation at many points throughout the plant and the reactor system are recorded on a centrally-located Speedomax multiple-point monitron recorder.

Instrumentation on the power-plant side is conventional. For instance, iron-constantan thermocouples measure temperatures throughout the steam cycle, recording them on a Speedomax multiple-point recorder.

Automatic. The two automatic systems in EBWR are both located in the steam cycle. One is a feedwater control and the other is a steam by-pass control.

The feedwater control incorporates an L&N servo-amplifier to position the main regulating valves. During operation, this control keeps a constant water level in the reactor. It is backed up by an optical level gage, watched by a television camera. The TV setup provides the operator with a visual indication of reactor level.

A steam by-pass arrangement is dictated by the positive feedback charac-



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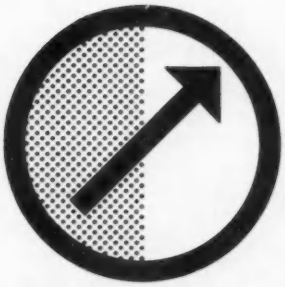
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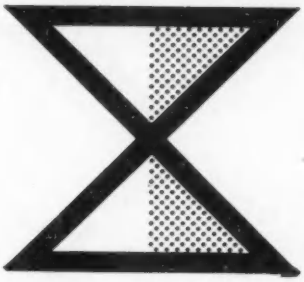


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Section 1647, Auburn, N. Y.

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teristics of the boiling-water reactor. When load on the turbine generator increases and the turbine draws more steam, the boiling reactor tends to deliver less if it is connected direct to the turbine. Here's what happens: when the load on the turbine increases, steam pressure drops. The reduced pressure increases the size of steam bubbles formed in the reactor, producing negative reactivity to lower power level and the steam delivered.

To prevent such a reaction, the reactor is operated at constant power level; steam is delivered to a by-pass arrangement, which divides it and sends the required amount to the turbine. The rest is by-passed direct to the condensers.

Safety's influence. Safety requirements have influenced a lot of the instrumentation in EBWR, as is to be expected. To cite a couple of examples: a complicated interlock system requires that 15 different conditions must be safe before the reactor can be started up. And in the plant system there are about 100 alarm points on the annunciator panels just above the console in the control room.

EBWR has at least one characteristic in common with other types of reactors: need for maximum reliability in instrumentation and control. In EBWR, the use of electronic instrumentation is minimized because of the reliability requirement. For critical measurements, the Argonne engineers use battery-powered D'Arsonval galvanometers. The battery power assures operation during a power failure.

More BWR. U. S. plans for future boiling-water reactor plants are well defined. EBWR was the third or fourth such plant built by Argonne; previous models had been confined to experimentation.

On the commercial side, GE's 5,000-kw boiling-water reactor—similar in many respects to EBWR—is nearing completion at Pleasanton, Calif.

GE is also designing a 180,000-kw boiling-water reactor plant to be built for Commonwealth Edison Co. of Chicago at Dresden, Ill.

Still another project is the 22,000-kw boiling-water power plant planned by the Rural Cooperative Power Association for Elk River, Miss.

And Allis-Chalmers has recently announced the start of a project to design a 60,000-kw plant using a controlled-circulation boiling-water reactor (CRBR), backed up with superheaters fired by conventional fuels.

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NEW BOOKS

Programming Theory

NUMERICAL METHODS. *Andrew D. Booth, reader in computational methods, University of London, 195 pp. Published by Butterworths Scientific Publications, London, England; sold in U.S. by Academic Press, New York. $6.00.*

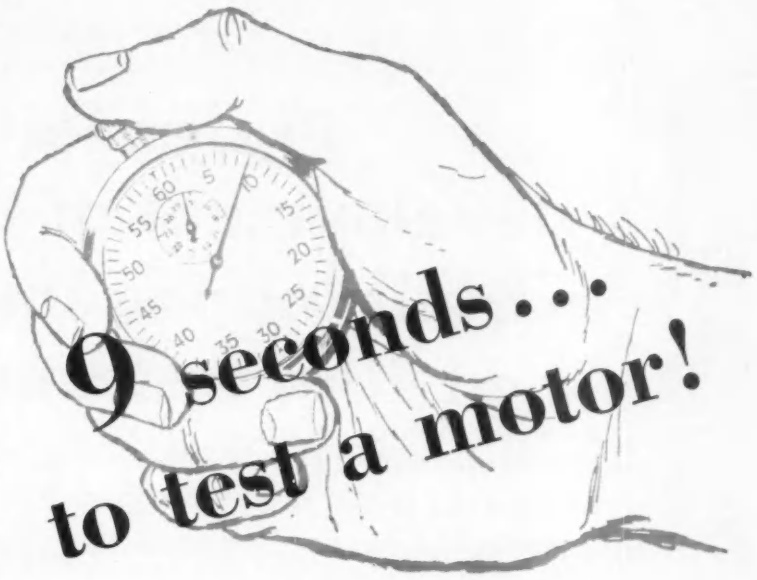
The purpose of this book, derived from a series of lectures given at Birbeck College, is "not so much to instruct in the detailed tedium of actual calculation, but rather to give an understanding of the basic principles upon which such analyses rest." Its scope was prompted "by the growth, during the past decade, of the science and art of programming for an automatic digital computer. The classic methods of hand calculation are, to a greater or less degree, unsuitable for modern machines and only by having a thorough knowledge of the underlying principles is the programmer likely to make effective use of the new mathematical tools."

For this reason, the book is directed toward those interested in simultaneous machine practice, for "at Birbeck College Computational Laboratory the teaching of numerical methods has been accompanied by the actual use of an automatic calculator, and demonstrations of such things as differencing and the solution of differential equations have been carried out by the machine and not by the student. Perhaps not unnaturally, this has proved more popular than the old methods."

It is this unique combination of purpose, scope, and direction that gives the book its essential merit and professional value. It is perhaps best read with a view to assimilating its broad features rather than its details —for the numerous topics are covered briefly and there are a number of inaccuracies in both mathematical statement and print.

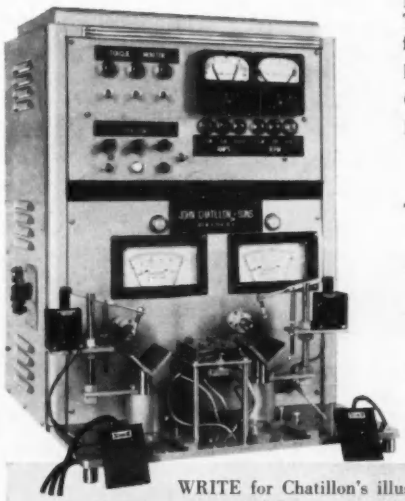
The usual topics, such as tabulations and differences, interpolation, numerical differentiation, and integration, series summation, ordinary differential equations, and simultaneous linear equations, are covered. But so are subjects not often treated: partial differential equations, nonlinear algebraic equations, approximating functions, and integral equations.

T. J. Higgins
University of Wisconsin
Madison, Wis.



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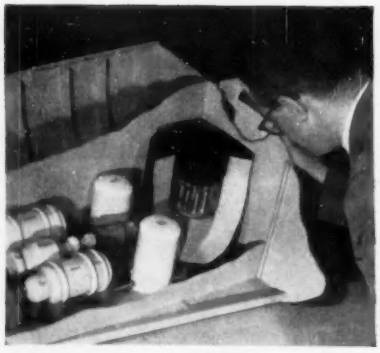
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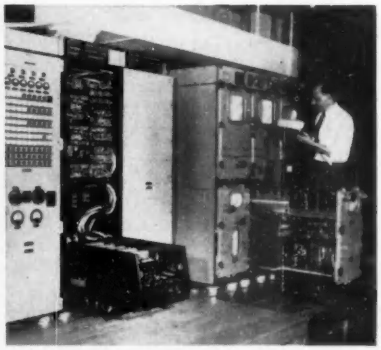
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CHEAPER ATOM POWER FOR THE SEA is a current Ford Instrument Company study in gas-cooled reactors for use in ships. The Atomic Energy Commission contract requires FICo to investigate the feasibility of building, by 1961, a power plant using this type of reactor to power an oil tanker. Ford also works on nuclear instrumentation.



ENVIRONMENTAL TEST CHAMBERS like the one above are used by Ford Instrument Company engineers in many projects involving design and development of equipment to be used at extreme altitudes or temperatures. Instruments for jet engines, for polar navigation, and Army and Navy fire control are FICo products.



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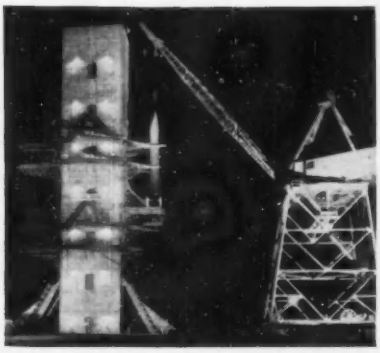
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TYPICAL OF FICo is its work in conjunction with the Army Ballistic Missile Agency on the guidance system for the Redstone Missile and the more advanced Jupiter Missile. Ford Instrument Company is also working closely with ABMA on research, development and design of more advanced systems.



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ABSTRACTS

Dynamic torque-meter

From "A Dynamic Torque-meter Utilizing the Reciprocal Wiedemann Effects" by M. J. O'Neill, The Perkin-Elmer Corp. AIEE paper CP 57-112, presented at the Winter General Meeting, New York, Jan. 21-25, 1957.

The instrumentation described by O'Neill to measure dynamic or transient torque in a shaft makes use of some relatively unknown magnetostrictive phenomena called the Reciprocal Wiedemann Effects. He begins by pointing out that strain gages, though unrivalled for measuring stationary torques, suffer from two drawbacks in measuring rotating torques:

- the normal operating stresses at the surface of the shaft, due to torsion alone, are between 300 and 1,000 psi —too small for strain gages, which are best applied where stresses reach 20,000 psi—hence the gage's bridge output voltage is very small
- these small voltages cannot be conveniently transferred through slip rings.

The strain gage output can be increased by decreasing the shaft's cross cross-sectional area, which increases the operating stress, but this alters the system's dynamic response and weakens the shaft mechanically.

O'Neill then describes an instrument that overcomes these drawbacks. "In the first place, torque measurement can be accomplished without any weakening of the rotating shaft; thus a permanent installation is possible, and the dynamic behavior of the system is unaffected. Secondly, the sensitivity of the device is considerably greater than that of the strain-gage torque-meter, and simpler instrumentation is required. Finally, torque measurement is possible over a wide range of magnitudes."

Figure 1 illustrates the basic equipment for implementing the First Wiedemann Effect. Here, an alternating current passes through a coil wound around a rod of magnetic material. Without torsion, no voltage appears along the rod. "When torsional moment is applied, however, a voltage will appear between the ends of the rod. The magnitude of this voltage can be predicted very closely from a knowledge of the longitudinal flux magnitude, the dimensions of the rod, the torque, and the linear magnetostrictive behavior of the material, as indicated by the equation:

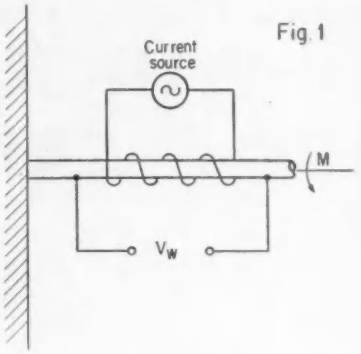


Fig. 1

$$V_w = \frac{32fL\epsilon\phi}{\pi D^4} M$$

"where f = frequency of excitation, cps
ϕ = longitudinal flux magnitude, webers rms
V_w = Wiedemann voltage, volts rms
M = applied torque, in.-lb
L = rod length between measuring points, in.
D = rod, OD, in.
ϵ = magnetostrictive stress constant of the material, approximately 2×10^{-5} psi^{-1} for pure iron."

A typical voltage response for this instrument to applied torque is shown in Figure 2. Here, two effects appear

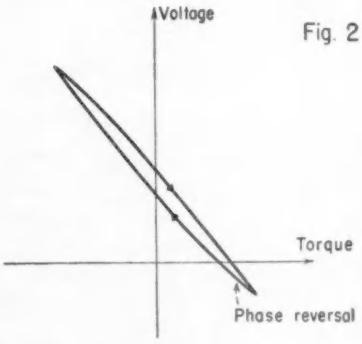
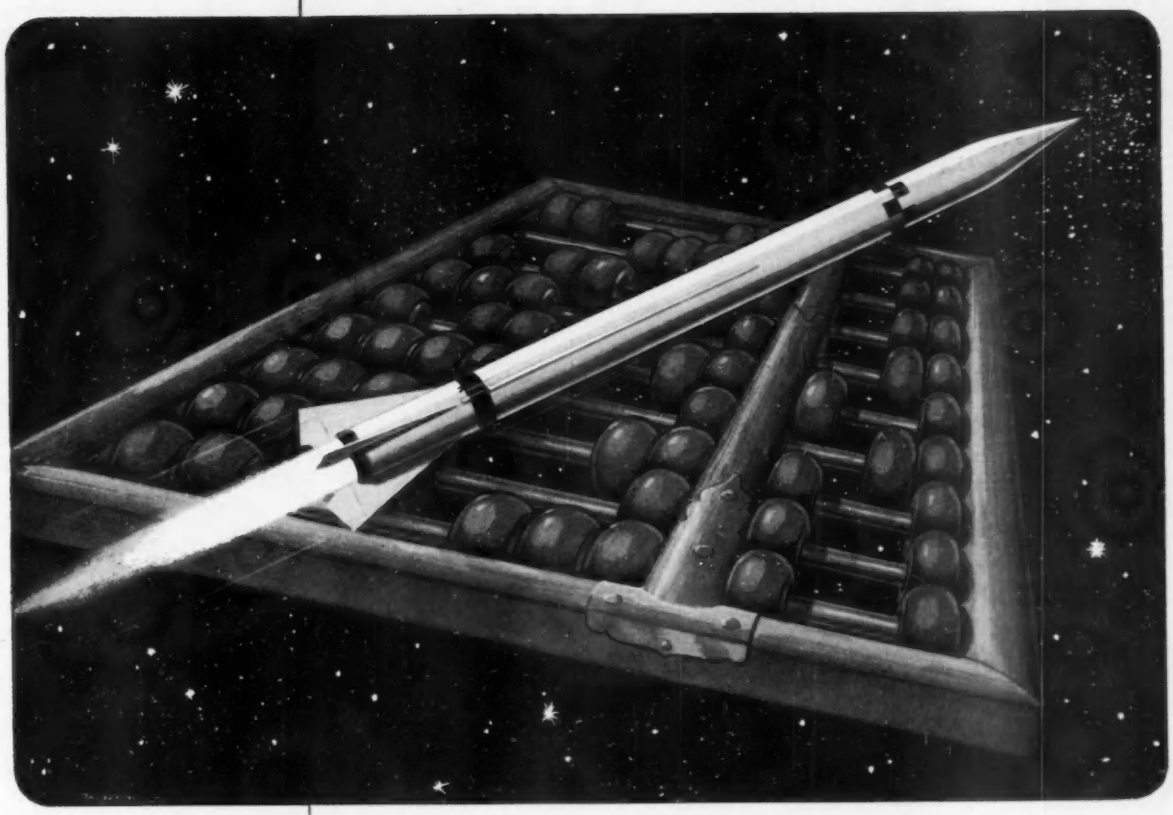


Fig. 2

that are not accounted for in the above equations: the voltage is in general not zero for zero applied torque and there is a pronounced hysteresis. These effects can be compensated or accounted for in present instrumentation, and may even be eliminated when current investigations are completed.

(The Second Wiedemann Effect is the converse of the first. That is, an alternating current is passed through the rod and the output voltage appears across the coil terminals. For solid rods the torque sensitivity is less than for the first effect, and the hysteresis is greater than for

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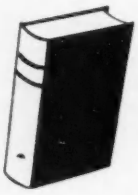
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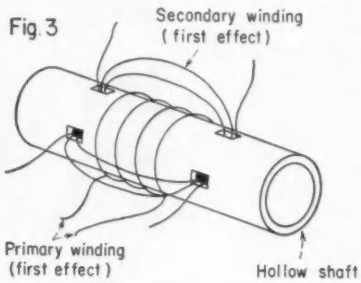
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ABSTRACTS

the first effect. In general, the second effect is not as satisfactory for measuring torque as is the first effect.)

The overall performance of the torque-meter is improved by going from a solid rod to a hollow shaft construction and using a secondary winding. In the above equation (for solid rods) the output voltage decreases inversely with the fourth power of outside diameter, so that increasing the diameter to meet torsional stiffness requirements radically decreases the sensitivity of the instrument. Decreasing shaft diameter increases the sensitivity, but decreases mechanical strength. By using a hollow shaft the dynamic performance requirements of the system are satisfied. Adding a secondary winding further increases the output voltage. Figure 3 shows a typical construction

Fig. 3



of the hollow-shaft torque-meter with a secondary winding. Here, the output voltage is given by:

$$V_e = \frac{32 f L e \phi N}{\pi (D^4 - D_i^4)} M$$

where D_i is the cylinder ID and N is the number of turns in the secondary winding.

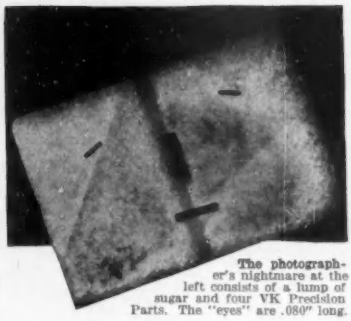
The author concedes that further investigation of the hysteresis problem is necessary. Certain other problems, such as the effect of frequency on sensitivity, and the effect of the mutual inductance between the secondary winding and the brush assembly, need to be looked into also.

Two-dimensional control

From "A Two-Dimensional Feedback Control System" by P. Sarachik and J. R. Ragazzini, Columbia University. AIEE paper 57-184, presented at the Winter General Meeting, New York, Jan. 21-25, 1957.

In this paper Sarachik and Ragazzini present "the concept of a control system in which the spatial perform-

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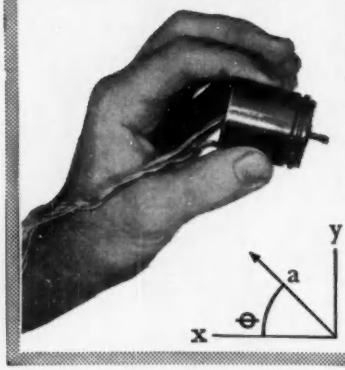
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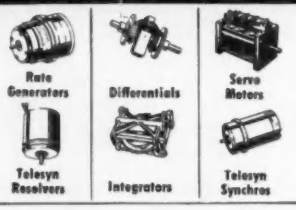
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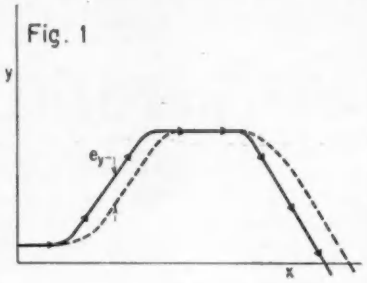


ABSTRACTS

ance rather than the time response is of primary importance. To achieve this type of operation the outputs of the system are cross-coupled with the aim of slowing down the motion in one dimension while speeding it up in the other, when the error tends to become too large. In this way both loops adjust properly to follow the desired two-dimensional space curve within prescribed specifications."

The authors illustrate the class of systems used to maintain the relationship between several variables by an automatically-controlled contour-cutting lathe control. The cutting tool traces a path in two dimensions, one in the direction of the bed movement and the other in the direction of the tool feed.

Figure 1 shows a typical prescribed



spatial path, where the solid curve indicates the desired spatial path and the dashed curve indicates the actual spatial path. "The relationship between x and y can be stored on such devices as cams, digital memory devices, or possibly as a mathematical function. In any such case, the storage device yields the desired value of y at its output when an input x is applied . . . It will be noted here that no specification is given as to when the controlled element should be at any given point in the path but only that it should be on or near the path within a specified amount."

The dependence, or cross-coupling, of y on x, such that an error in y affects both x and y, is shown in Figure 2. Here, the magnitude of e_y (see Figure 1) reduces proportionally the velocity in the x-direction until the velocity reaches zero when the error reaches its maximum allowable value.

In Figure 2 "the desired function to be followed by the controlled elements is stored in a data store of any form. When the store is interrogated by a signal x_e, it will deliver a signal y_R which is related by the desired func-

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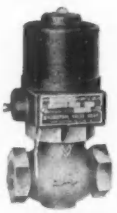
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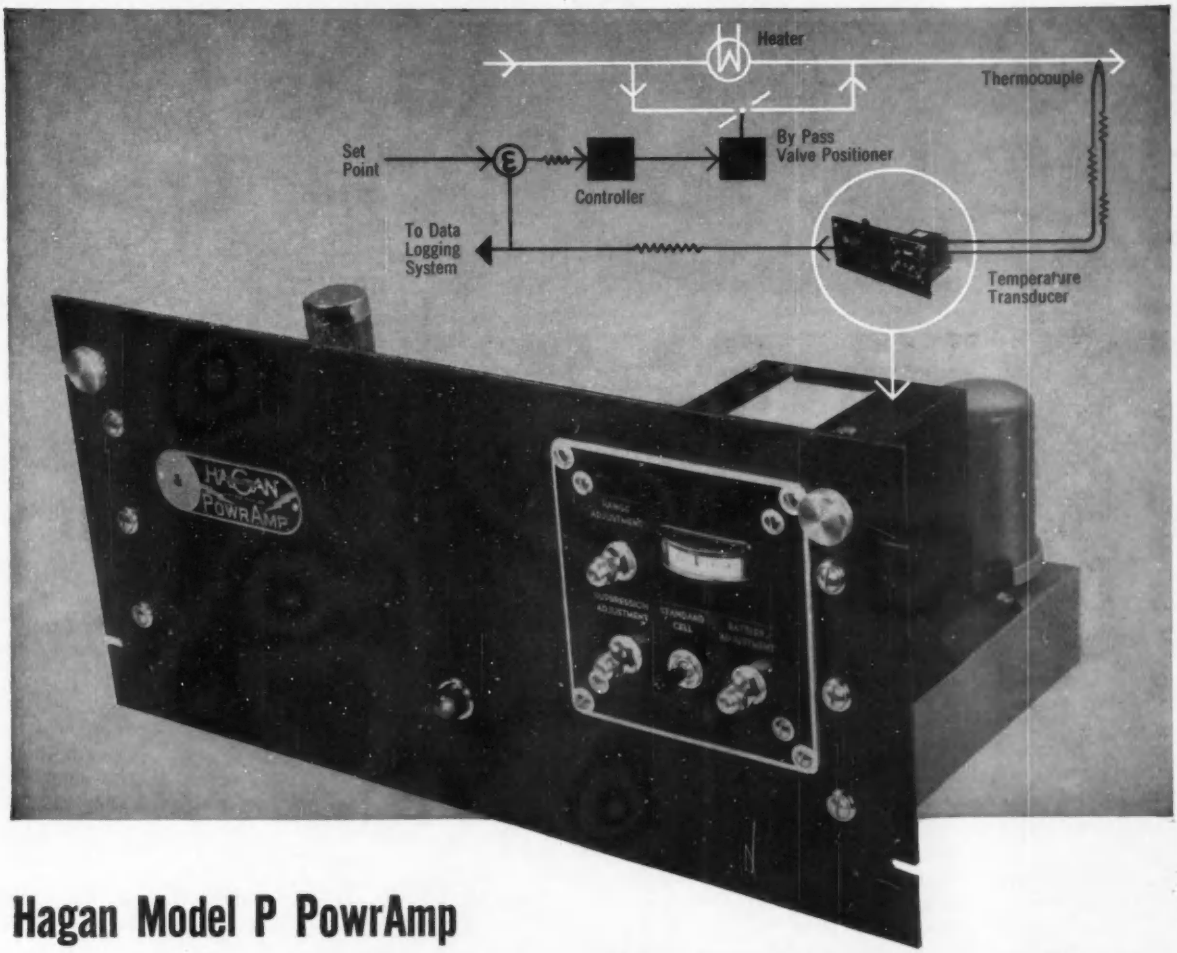
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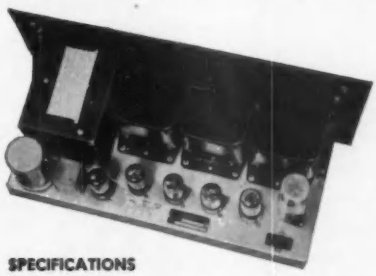
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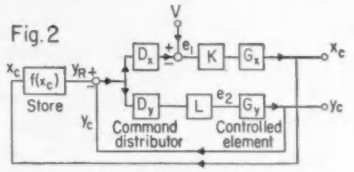
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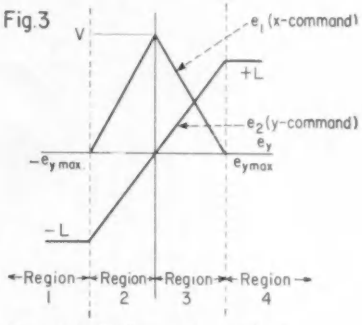
tion $f(x_c)$. The error detector compares the desired value of y with the



Block diagram of typical two-dimensional control system

actual value y_c and a control error e_y is generated by taking the difference. The interaction between the two dimensions is provided by a command distributor, D_x and D_y, which apportions the command to the x and y controlled elements G_x and G_y. The block L indicates a limiter which sets the upper value of the input e_2 to the controlled element. In this way, an upper speed of movement in the y-direction can be set at will. . . . The input V sets the maximum value of the input to the controlled element G_x. . . the maximum is reached when the control error e, is zero."

Figure 3 shows the combined com-



Command distributor characteristic

mand distributor function on which the operation depends. When e_y is zero the command to the controlled element G_x is maximum and the speed in the x-direction is maximum. But the magnitude of command in the x-direction decreases with an increase in error until the x-speed is zero. The y-speed is limited at L so that the tool carriage remains stationary until the error reduces below its allowable maximum value.

For a rigorous analysis of this control concept the authors determine the slopes of the phase-plane trajectories (they assume a second-order system) in the four regions of interest shown in Figure 3. In addition, they arrive at an equation describing the error in contour-following due to the

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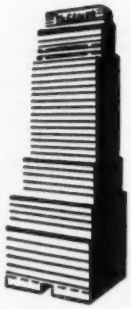
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dynamics of the system. A further section analyzes this system on a linear incremental basis for additional discussion of the dynamics, stability, and design considerations. The next section explains how to choose certain system parameters to meet desired performance specifications. Since some of the interrelating equations are not readily solvable by manual means, an analog computer setup is used to verify some of the conclusions previously arrived at by straight reasoning and physical considerations.

Quotes on data-logging

From "Proceedings of the 1956 Symposium on Automatic Data Logging System." Sponsored by the Philadelphia Section, Inc., Instrument Society of America, Nov. 7-8, 1956.

Introduction to Process Data Logging by J. E. Read, E. I. duPont de Nemours & Co., Inc.: "Here is perhaps our greatest potential use for the principle embodied in the process data logging system. In the system we have built up here for Management's consideration, we have accurate signals, in either analog or digital form (or both) measured in point of time not farther from one another than one scanning cycle. This state of affairs requires no further suggestion on our part—the technical man is way ahead of us—computation! . . .

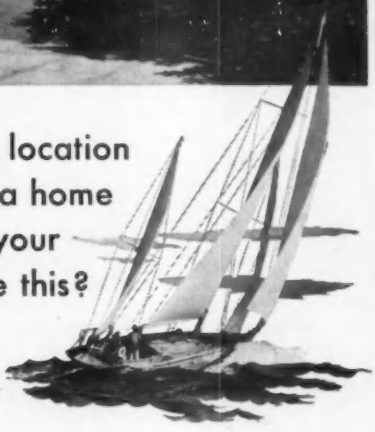
"We have chosen to suggest a local single purchase computer, perhaps for automatic calculation of unit conversion efficiency or overall system yield, say, on an hourly basis. However, this information might be simply encoded each hour along with appropriate composition analysis values, for computation at a headquarters location supervising a multi-plant operation. Where more than one plant is involved for the same product, this computation might include an answer on optimum production rates for minimum inventory and best overall company efficiency. So let this be our introduction to the technical superintendent—although obviously we would soon be suggesting automatic reset of process controls based on computer results if we extrapolated this point much farther."

Basic Definitions of Automatic Data Logging Systems by Norbert E. Weber, Fischer & Porter Co.: "A component which performs only one operation can be rated in numbers of operations it is expected to perform or in

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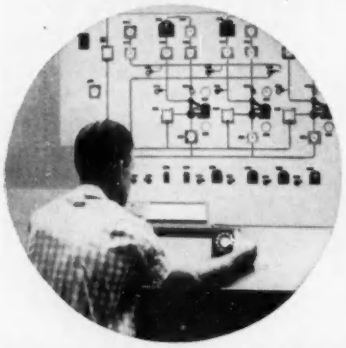
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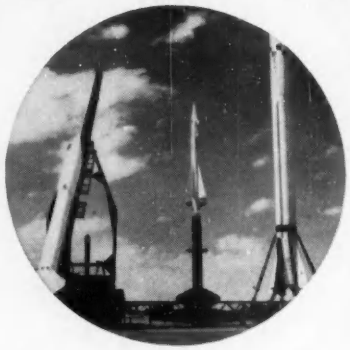
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terms of hours of useful life. A complex system containing many types of such components has to be more carefully evaluated as to life expectancy. We have seen that some loggers use the stepping switch 100 times where others only use it once to accomplish the same purpose. There are many similar examples. The whole question of logger life expectancy must be examined in the light of cost, convenience, ease of replacement and predictability of performance. Rather than use an expensive long-life component, it may be more advisable to use a component with a lesser but predictable life expectancy and design it into the system for convenient replacement on a preventive maintenance schedule."

The Use of Transducers and Transmitters in Digital Data Handling System by John Werme, Metrotype Corp.: "A third area which must be considered is where the data handling system is independent of the normal instrumentation. All transducers and transmitters are picked for use with the digital system alone. This is the usual state of affairs in the aircraft and missile field and in certain other testing areas, and accounts for the high degree of success of some of these installations. No such installation exists in the process industry to my knowledge, and there are two schools of thought on the subject of eventual possibility of such a system. Some claim that process control and accounting will always be a collection of small, closed loop control systems with the set points adjusted and set by automatic means while others maintain that eventually we will have a unit controller which receives all process variable information and adjusts all final control elements. This question, intriguing as it is, will not be answered soon. . . . It is sufficient to note that if the latter course is followed, that today's digital data handling system may well be the input-output of the unit controller."

Analog-to-Digital Conversion by Noel B. Braymer, Beckman Instruments, Inc.: "The initial cost, the capacity, the life expectancy, and the reliability of the data system will depend not only on the caliber of the hardware in the design, but in large measure upon the utilization of that hardware. The hardware will be efficiently utilized only if the fundamental principles used are inherently efficient . . ."

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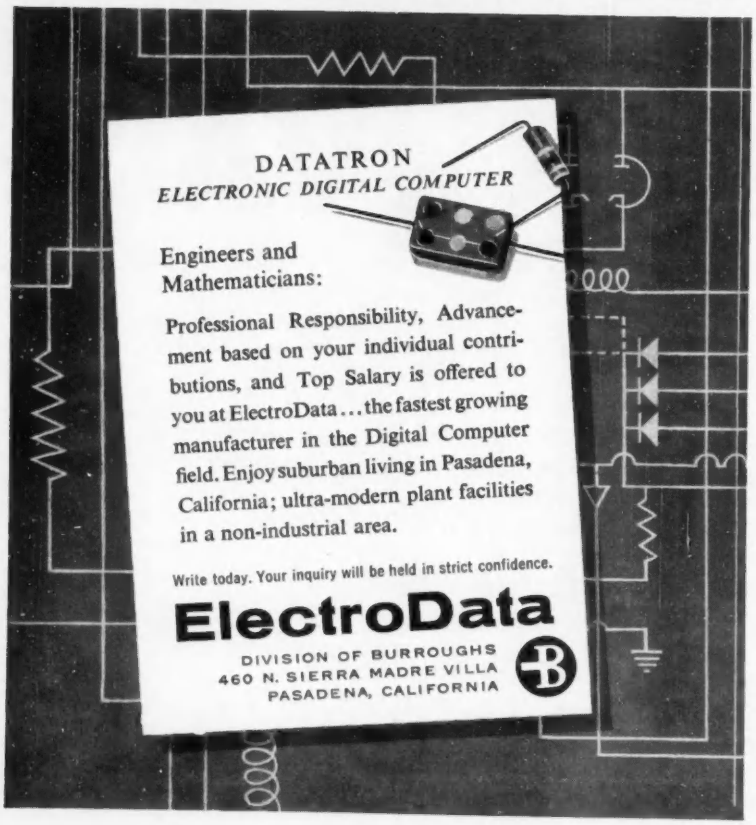
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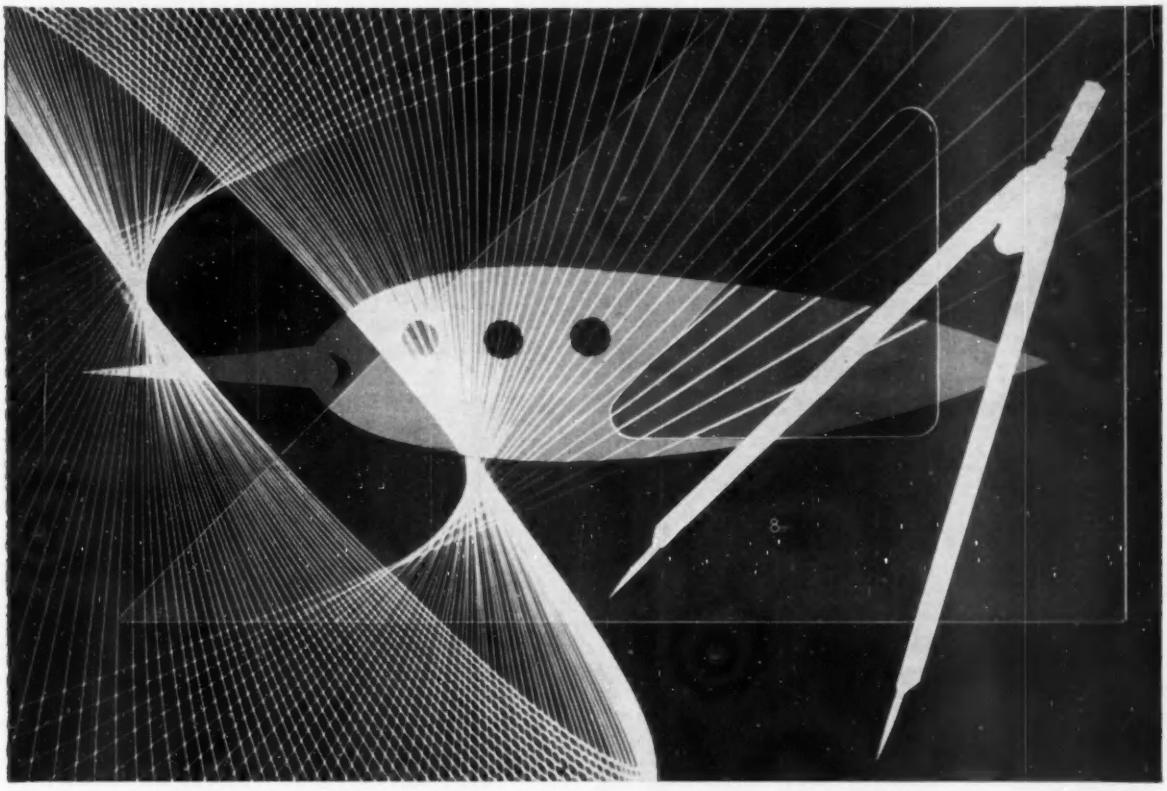
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Source of Information for Process and Accounting Calculations by Arthur Freilich, William Doherty, and Donald Stevens, Burroughs Corp.: "In order to obtain maximum benefit from "on-line" computation, the reliability of the computer must be high, approaching that of conventional instrumentation. This appears to be attainable through the use of solid state techniques utilizing transistors and bistable magnetic cores in the circuits of the computer.

"Use of the 'on-line' computer gives the operator data which were previously impossible to obtain until days or weeks after the conditions actually existed. Control of the process does not have to depend upon empirical settings of the controllers but can be based upon the operating guides. . . .

"In addition, the 'on-line' computer will lead to a better understanding of processes and the inter-relationships of the primary variables. The ability to determine the immediate effect of a change in primary variables on the operating guides will lead to new settings of the analog controllers to obtain efficiencies and yields which are not consistently attainable today. . . .

The Future of Data Logging in the Process Industries by Paul W. Knaplund, International Business Machines Corp.: "The two accelerating factors to be analyzed are the use of data logging as a tool in fundamental research and design, and as a principal component in automatic control systems. In order to evaluate these applications, we must first admit dissatisfaction with limitation of our present knowledge of process dynamics and control. These limitations require conservatism in the design of plant facilities and in the selection of control methods. The consequences are increased cost of construction, and reduced efficiency in operation. It is often said that the process industries are rapidly moving toward the use of automatically operated dynamic control systems that will make possible the continuous operation of major facilities at optimum levels of product quality, output quantity, and plant efficiency. The design of such control systems must be preceded by greatly increased understanding of the processes to be controlled. This understanding, which must be gained with the assistance of automatic data logging techniques, will give both the designer and the plant manager new opportunities for cost reduction."



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Jack Wittkopf was Associate Professor of Electrical Engineering at Oregon State for 6 years before he joined Autonetics in 1951. Now Group Leader in computers and electronics, Jack lives with his wife and four children in Autonetic's home town of Downey, California, where his spare time activities include photography and ham radio.

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MARCH

Institute of Radio Engineers, 1957 National Convention and Exhibition, N. Y. Coliseum and Hotel Waldorf-Astoria, New York March 18-21

Nineteenth Annual American Power Conference, Hotel Sherman, Chicago March 27-29

APRIL

New Jersey Section of Instrument Society of America, Ninth Annual Symposium (subject: "Process Fluid Analyzers"), Hotel Essex House, Newark April 2

American Society of Mechanincal Engineers, Instruments & Regulators Div. (IRD) Third Annual Conference, Northwestern University, Evanston, Ill. New date-April 7-10

American Society of Mechanical Engineers, Spring Meeting, Dinkler-Tutwiler Hotel, Birmingham, Ala. April 8-10

Semi-centennial Celebration, Pace College, New York City April 10

Instrument Society of America, National Nuclear Instrumentation Conference, and Third Southeastern Regional Exhibit, Atlanta Biltmore Hotel, Atlanta, Ga. April 10-12

Second National Simulation Conference, and Ninth Southwestern Institute of Radio Engineers Conference and Electronics Show, Shamrock Hotel, Houston, Texas April 11-13

Second National Industrial Research Conference, "Research for Profit", sponsored by Armour Research Foundation of Illinois Institute of Technology, Conrad Hilton Hotel, Chicago April 24-25

Seventh Region Institute of Radio Engineers Conference, Balboa Park, San Diego, Calif. April 24-26

Third National Flight Test Symposium (no exhibits), Hotel Statler, Los Angeles April 29-May 2

MAY

Electronic Components Symposium (sponsors: AIEE, IRE, Radio-Electronics-Television Mfgrs. Association, West Coast Electronic Mfrs. Association), Morrison Hotel, Chicago May 1-3

Fluid Control Institute, Greenbriar, White Sulphur Springs, W. Va. May 8-11

National Telemetering Conference, (inspection trip to White Sands Proving Grounds), Hotel Cortez, El Paso, Texas May 27-29

JUNE

Institute of Radio Engineers, First National Symposium on Production Techniques, Hotel Willard, Washington, D. C. June 6-7

American Society of Mechanical Engineers, Semi-annual Meeting, Hotel Sheraton-Palace, San Francisco June 9-13

Institute of Radio Engineers, National Conference of Professional Group on Military Electronics (some sessions classified "confidential"), Sheraton-Park Hotel, Washington, D. C. June 9-15

Instrument Society of America, Third National Symposium on Instrumental Methods of Analysis, University of Chicago June 13-15

American Institute of Electrical Engineers, Summer General Meeting, Sheraton-Mt. Royal, Montreal, Quebec, Canada June 24-28



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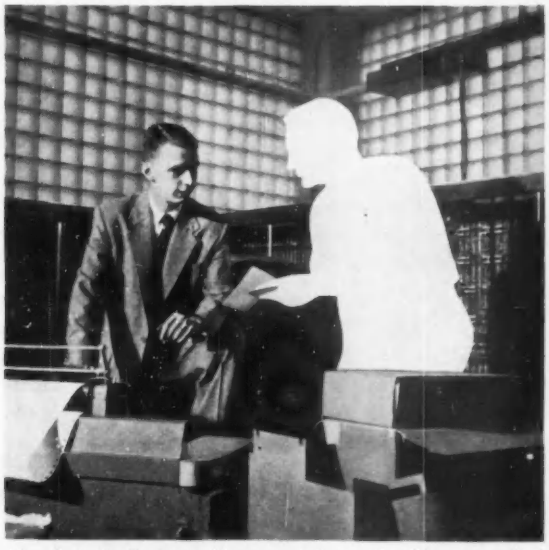
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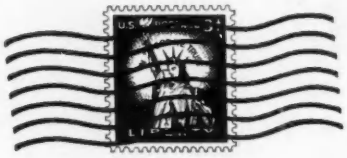
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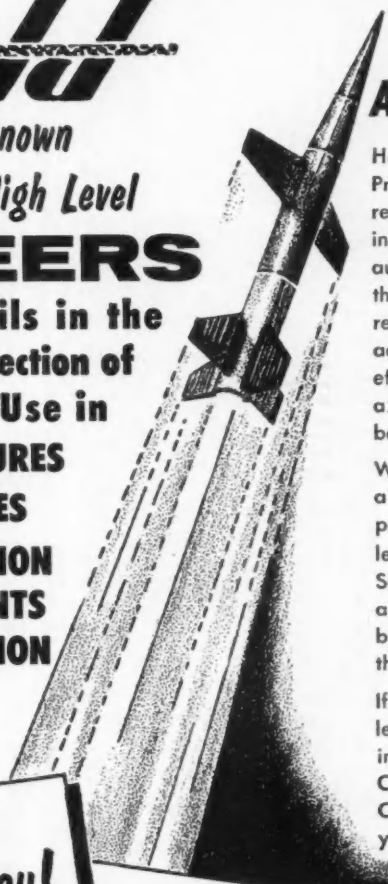
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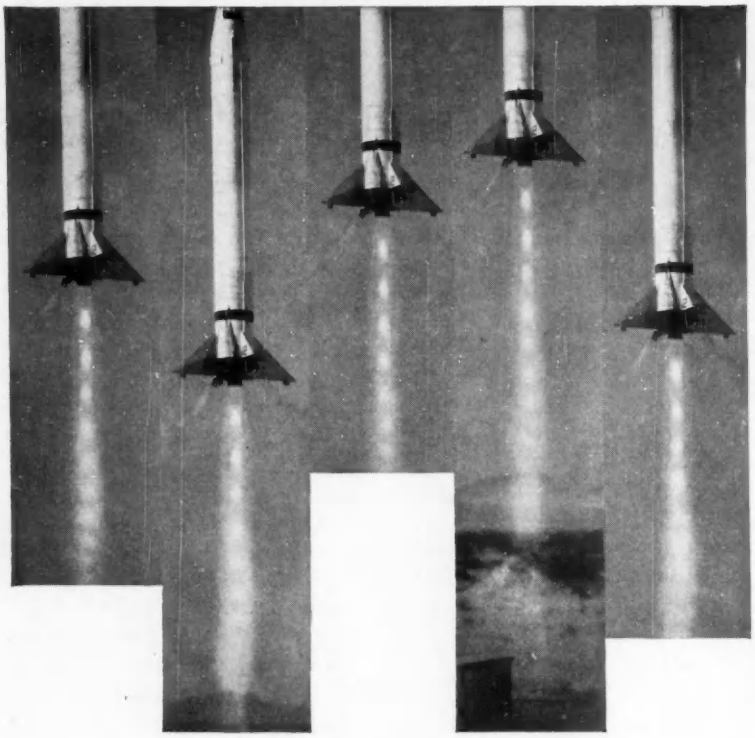
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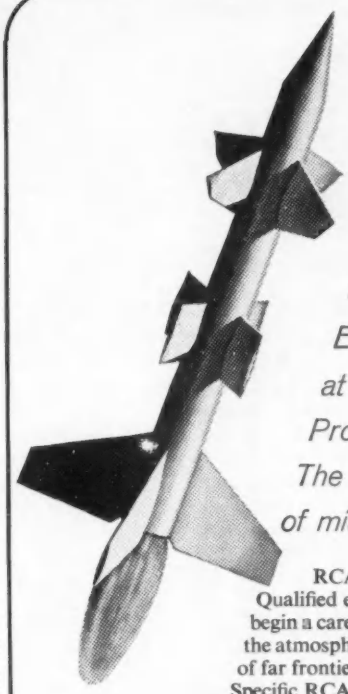
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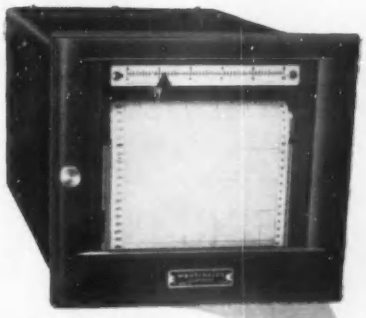
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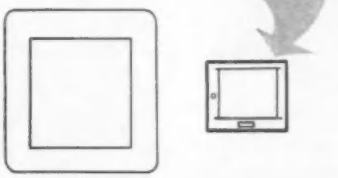
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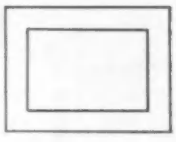
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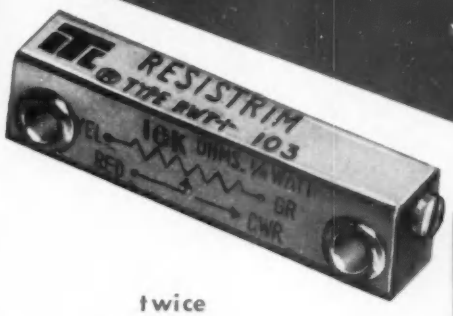
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The RWT is now in full production. This latest addition to TIC's precision trimmer potentiometer line — most complete in the industry — provides a high-power, low-cost, stable, and compact unit for fixed-gain adjustments . . . padding . . . critical bias . . . and balancing adjustments.

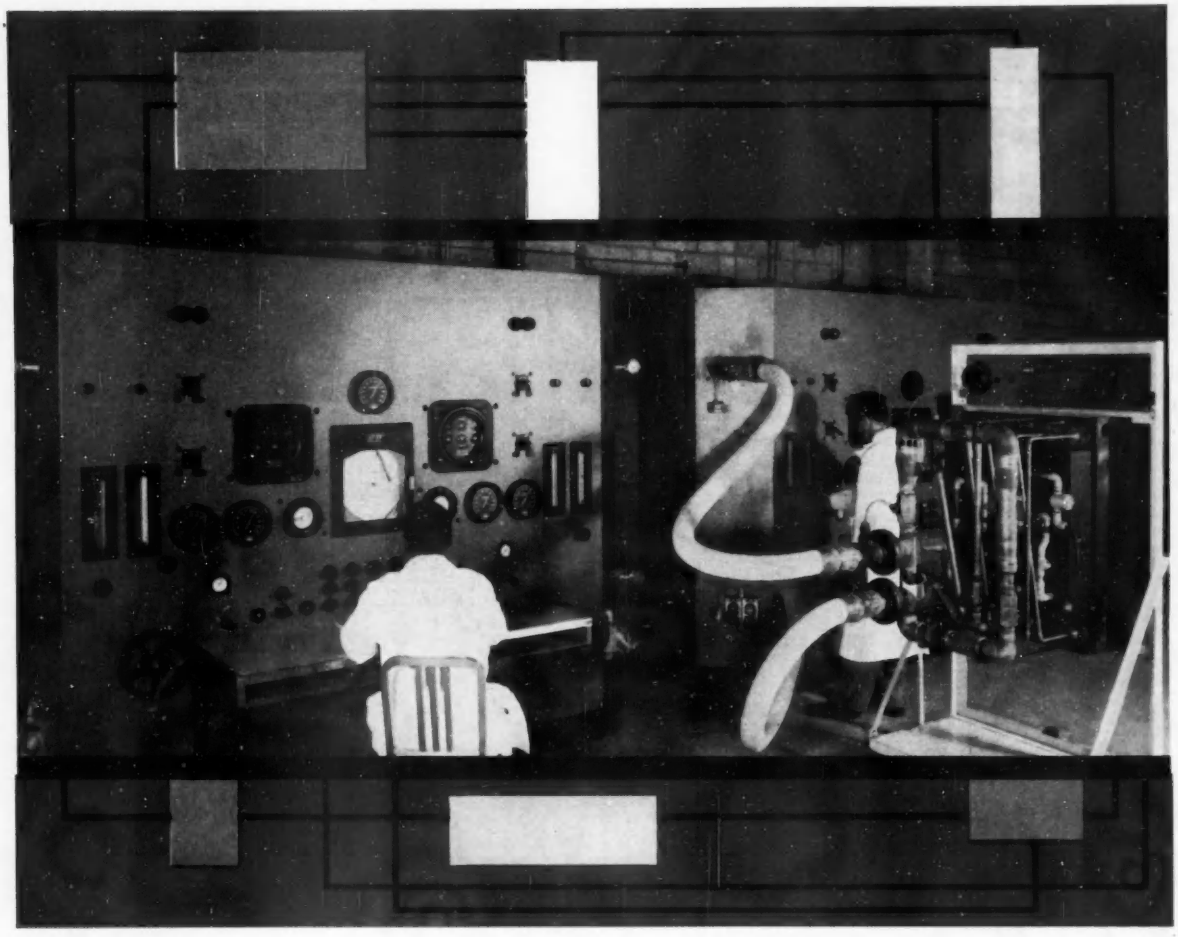
The wire-wound RWT incorporates the advanced mechanical design of the popular TIC RFT Metlfilm Trimmer. Permits precise trimming with a unit less than 1/10 of cubic inch in volume. Advanced mechanical design provides: Complete environmental protection with one-piece anodized aluminum base and sealed stainless-steel cover . . . less than 4/10 ounce in weight . . . and precise stable adjustment with a 25-turn, stainless-steel lead screw.

RWT provides standard temperature range from −55°C to +95°C . . . wide resistance range from 50 to 20K ohms . . . and a power rating of 2 watts at 25°C derated to 1/4 watt at 95°C. Special units are also available for operation up to +145°C and power ratings up to 1/4 watt at 125°C.

For complete specifications on the RWT request Bulletin TP-200.

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